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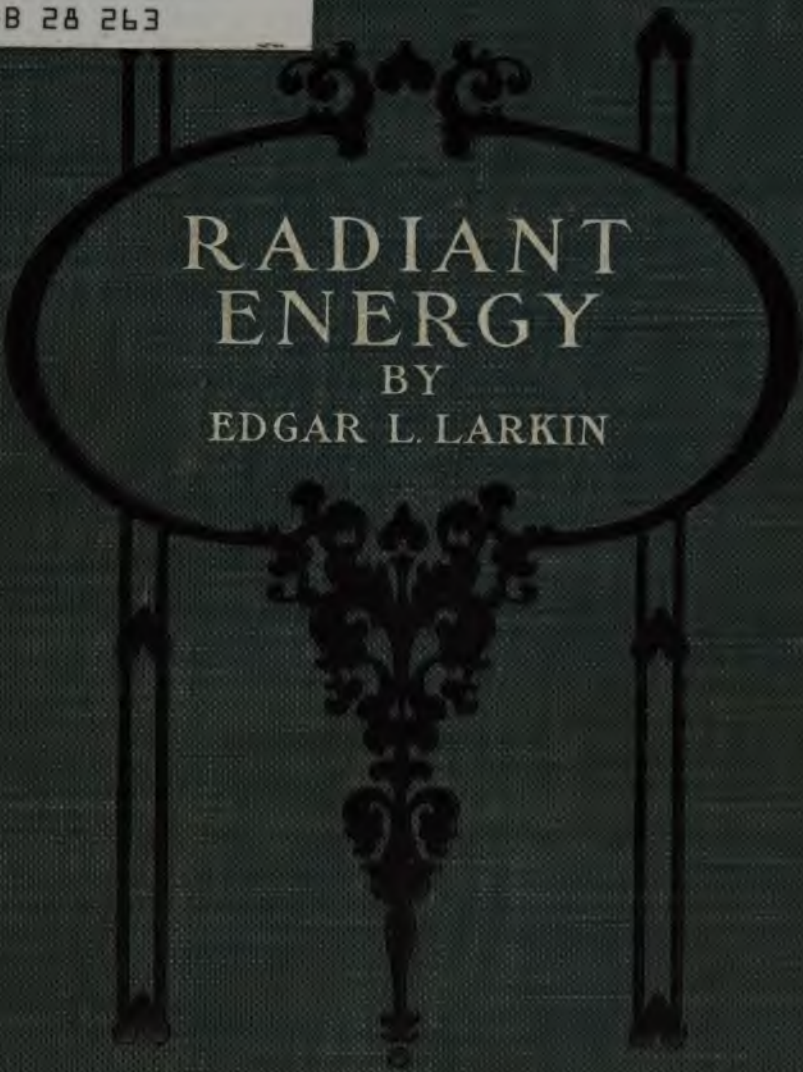
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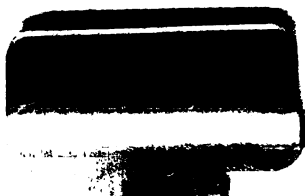
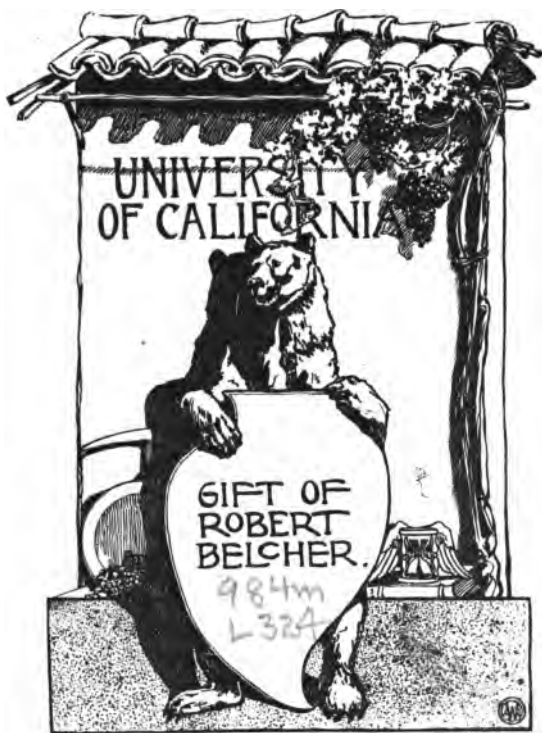
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A large, ornate, dark-colored frame with a central oval opening. The frame features intricate scrollwork and floral patterns at the top, bottom, and sides. The text is centered within the oval opening.

RADIANT ENERGY

BY
EDGAR L. LARKIN

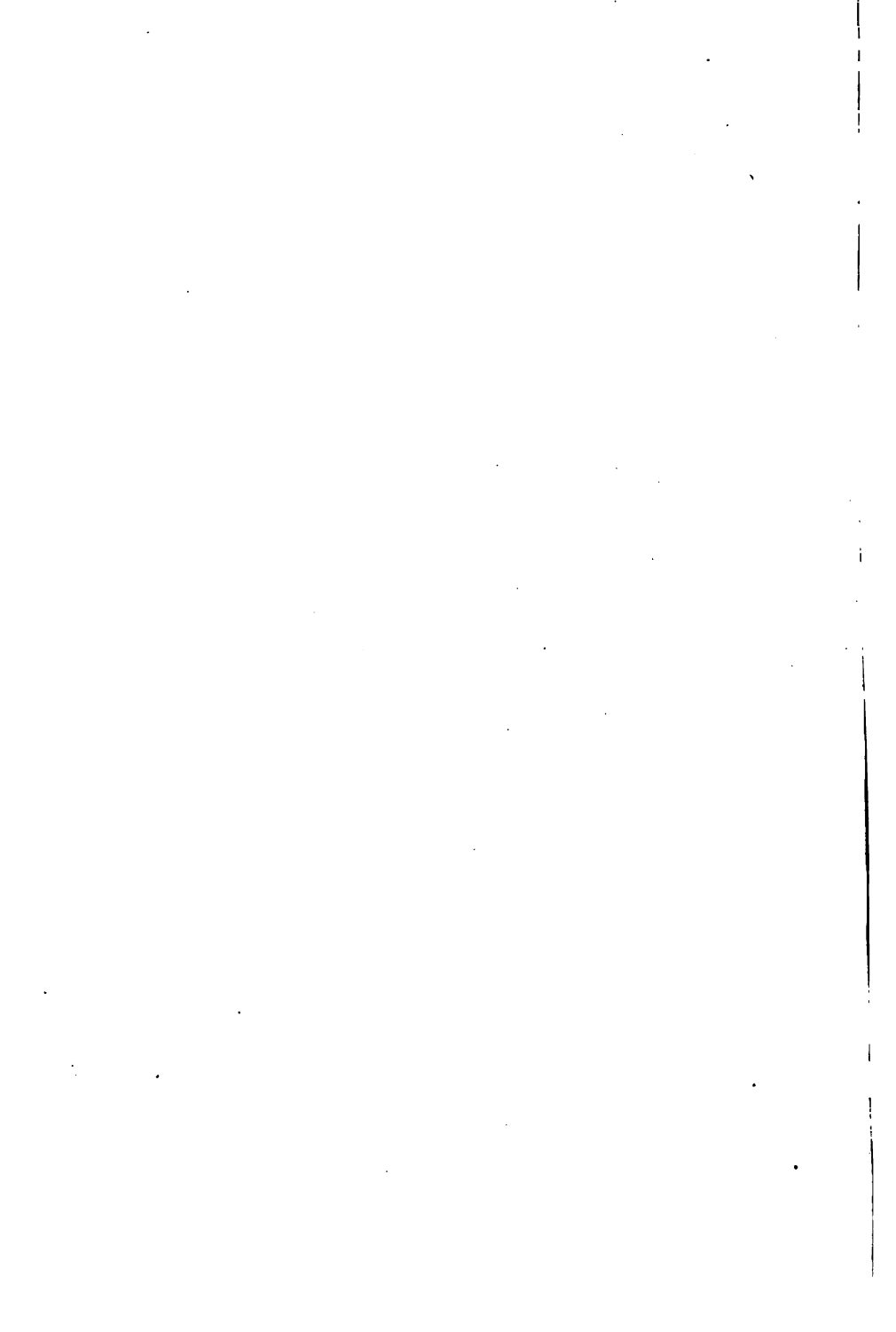
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**The Great Nebula in Andromeda, from a photograph by
Professor G. W. Ritchie of the Yerkes Observatory.**

RADIANT ENERGY

AND ITS ANALYSIS

ITS RELATION TO MODERN ASTROPHYSICS

BY

EDGAR L. LARKIN

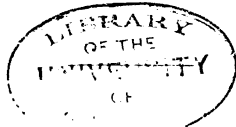
DIRECTOR LOWE OBSERVATORY
ECHO MOUNTAIN, CALIFORNIA

Fellow of the American Association for the Advancement of Science
Member of the Astronomical Society of the Pacific
Fellow of the Southern California Academy of Sciences

ILLUSTRATED

"Many thousands of unrecorded nebulae exist in the sky. A conservative estimate places the number within reach of the Crossley reflector at about 120,000."—*James E. Keeler*.

"Darkness there was, and all at first was veiled in gloom profound, an ocean without light."—*Rig Veda, 10th Ch., Hymn 129*.



1903
BAUMGARDT PUBLISHING COMPANY
LOS ANGELES, CALIFORNIA

BELCHER

J. Arson

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TO
JOHN D. HOOKER

WHO IN THE MIDST OF THE PRESSING DUTIES
OF A BUSINESS CAREER STILL FINDS
TIME TO DEVOTE TO SCIENCE
AND ITS ADVANCEMENT
IN SOUTHERN
CALIFORNIA

THIS BOOK IS DEDICATED

175984

INTRODUCTORY.

Upon coming to the Pacific Coast, the writer was engaged by Dent H. Robert, editor of the San Francisco Examiner, to contribute a series on modern physical science. The subject selected was, "Radiant Energy and Its Analysis," together with its application to astronomy and astro-physics—the latter being an entirely new branch of research into the laws of nature. The text as it appears here, and also the cuts, appeared in the Examiner, from February to August, 1902. The writer received so many letters on the subject matter of the series, and upon the discussions therein and questions involved, that it was desired that the whole should be published in book form. The matter was considered by the officers, William H. Knight, President, and B. R. Baumgardt, Secretary, and many of the members of the Southern California Academy of Sciences. No funds were in sight, so the Vice-President, J. D. Hooker, came to the rescue and said he would see the book through the press. For this, he not only has the thanks of the writer, but of the members of the Academy also. Special regard is gratefully accorded

INTRODUCTORY

to those two eminent women, the Misses Matilda H. and Jennie M. Smith, of Allegheny, Pennsylvania, for their beautiful present of a spectrograph and heliostat. These splendid instruments were made by that accomplished mechanic, John A. Brashear, of Allegheny, and presented to the writer upon their order. Here is a case where two wealthy women devote their time and means to the cause of science and the aid of research into the most inscrutable laws of the natural world.

To the Baumgardt Publishing Co. is due the credit of a perfect publication, in composition, arrangement and high-class press work. Thanks are tendered to Mausard, Collier & Co. of Los Angeles for their fine production of many of the cuts. In many cases the originals were very poor, some scarcely legible. The Lick Observatory, Mount Hamilton, Calif., also kindly furnished the pictures of their telescope and spectrographs.

Thanks are due to Professor E. E. Barnard of the Yerkes Observatory for the exceptionally fine graphs of the Milky Way and of the great Nebula in Andromeda, as well as of the telescope and spectrograph in that observatory. The graphs of the solar prominences secured on the eclipse expedition are of great beauty and perfection. These pictures were prepared by Ferdinand Ellerman, the observatory photographer.

Acknowledgements are due to William H. Knight of Los Angeles for reviewing the work, critically examining the whole and noting imperfections.

Since the beginning of the series, the astro-physicists of the world have made many more researches and discoveries. Enough material is now on hand from all these to fill another volume

INTRODUCTORY

like this. The scientific brain of the world is in a state of intense activity, the most recondite and elaborate studies are under way—and knowledge is moving with ever-increasing momentum. The most skillful detectives of nature are at work hourly in every possible way, striving to find out what matter is, and also energy. At present both are unknown; they may forever remain unknown, but if it can be proven that they are unknowable, this at least would afford a resting place for wandering thought, wandering along the borders of infinity.

EDGAR L. LARKIN.



I.

RADIANT ENERGY.

"Our fathers resorted to Indra of old: they discovered the hidden light and caused the dawn to rise."—Rig Veda. Muir's Sanskrit, Texts 39-2. I 48, 14.

Radiant here means proceeding from a center in straight lines in every direction. Energy is internal and inherent. Professor Barker, Physics, page 4, says: "Energy is defined as a condition of matter in virtue of which any definite portion may effect changes in any other definite portion." This was written in 1892, and discoveries since confirm it. Energy, then, is a state of matter, or, rather, the result of a particular state or condition in which matter may be when any observed phase of energy appears.

These two, matter and energy, or, possibly one, is the sum total of all that has been found during three centuries of incessant research in all that portion of the universe visible in a forty-inch telescope armed with the most powerful spectroscope ever made.

It is the belief of the writer that all this space is saturated with inconceivably minute corpuscles, those recently discovered by Professor J. J. Thomson. These are doubtless either electricity in its ultimate refinement, or very closely allied to it, or its immediate carriers. The smallest particle of hydrogen, long time called an "atom," has been thought to be the least in mass of any known particle of matter; but the corpuscles detected by Thomson have

only one-thousandth of the mass of the hydrogen atom. The earth and sun, all suns and dark bodies in space, all granular matter move through the primordial cosmical mass of electrical corpuscles as would a wire screen through water. The wide spaces in diamond, glass, steel, flint or anything else allow these "bodies smaller than atoms," as Thomson calls them, to pass through.

From the record-breaking discoveries of the physicists Curie, in previously unknown waves, it is coming to be seen that all matter is radio-active. All phases of matter, such as radium, barium, uranium, thorium, polonium, vanadium, cerium, molybdenum, zinc, aluminum, etc., emit obscure undulations, and these imprint radiographs on sensitive photographic plates.

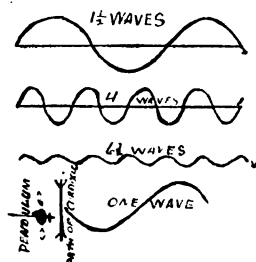
Radium is so active that its potential has been measured and with a delicate watt meter its power has been determined. Thomson's corpuscles are plus and minus in their electrical charges, the positive carriers of electricity being comparable in size to ordinary atoms of gross matter; but the corpuscles that flow between the atoms of all types of matter are negative. The corpuscles emitted by radium are negative and can be bent out of their course by the plus pole of a magnet—so that active matter sends out perpetually the same kind of corpuscles that fill all space. It is incredible that these radiating bodies forever emit corpuscles without receiving them from the primeval store. Therefore radio-active masses are simply more transparent to corpuscles from space than others, or change their directions of motion.

The fact that negative ions can be deflected by magnets is one hidden deep in the end of a long corridor in nature, a passage more inscrutable than those in the Pyramid of Suphis.

TRANSMISSION.

From the definition of energy it is the potential of the universe. When matter is in a phase allowing it to be active, it effects other quantities of matter at a distance. The method of

transfer is known to be by means of wave motion. Each impulse moves from the emitting to the receiving mass on a rigorously straight line. One continuous set of oscillations in this right line is called a ray. Each negative or Thomsonian corpuscle makes a double vibration to and fro like a pendulum straight across the direction of the ray—i. e., at right angles to it, the corpuscle moves over and returns to its original position had before the excursion. Since the corpuscles are negative and can be drawn out of their original straight path by the action of magnetism, the entire wave motion of the universe is electro-magnetic. This is what Maxwell prophesied forty years ago. Thomson fulfilled the prophecy.



Cut 1. Waves.

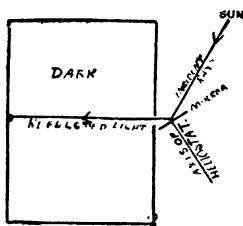
After one corpuscle makes an oscillation across the direction of the ray and return the next does likewise, and the next, and so on. After the first corpuscle makes swing, another distant from it 186,000 miles in the same straight line will also make a vibration at the end of the first second of time.

In figure 1, cut 1, the distances of the sides of the waves from the central straight line of the ray is amplitude, or the distance each corpuscle swings on either side. Since each wave must be distant from its source, 186,000 miles at the end of one second, it follows that variations in the lengths of the waves occur, those having the greatest amplitude being the longest—

that is, a less number will be contained in a centimeter, as shown in diagram. Really there is no such thing as a ray; the straight line along the middle of each set of waves was simply drawn to show direction of the waves and to show the amplitudes on either side. A cannon ball carries matter and energy while corpuscular disturbances transmit energy from an active phase of matter to a passive or receiving, non-vibrating phase. If one inch contains from 34,000 to 61,000 electro-magnetic undulations, their effect on human sensation is called

LIGHT.

With 34,000 to the inch, everybody agrees in saying they see red; if 61,000, violet, with an indefinite number of colors between.



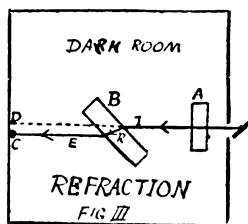
Cut 2. Dark Room. Light Entering from Sun.

For physicists to examine the properties of light it must be first bent out of its course. The best place to work is in a dark room, where all light is excluded except one pencil of waves admitted through a minute opening.

In cut 2, a band of light is shown coming from the mirror of a heliostat. The bundle of waves crosses the room and makes a bright image of the aperture on a white screen. The heliostat mirror is turned by a clock one way as fast as the earth turns the other, so the light is in the room from sunrise to sunset. That is, the sun seems to be at rest in space, hence the name of "sun standstill."

TURNING WAVES OUT OF THEIR COURSE.

In figure 3, of any transparent substance is placed in the beam of waves at right angles to it as at A, no effect is produced; the white spot is still seen on the screen. But incline the transmitting body as at B and a marvelous thing is seen—the bright spot moves aside. This has elicited the admiration of every physicist from Newton to the present. It is a fundamental rock-hewn foundation stone of nature. Without it no telescope, microscope, camera or spectroscope or any lens whatever could be made—and men would now be in complete ignorance of the universe round about. The waves at I are incident, at R refracted, and



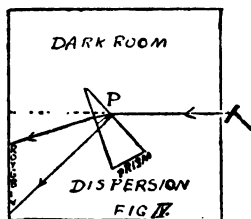
Cut 3. Refraction of Light by Inclined Medium.

at E emergent, but the entering and leaving bands are parallel; the emergent line of waves being bodily shifted aside, their motion coming to an end in the bright spot C, having moved from D. This phenomenon is called refraction—to bend or break. The diameter of the bright dot on the screen, however, is the same at C and D. The light yet is not in a condition to analyze.

Instead of putting a flat medium with parallel lines in the waves as at B, insert one with inclined sides as at P, figure 4. The emergent band instantly widens, the bright spot vanishes, a broad and long band of light containing every color from red to violet flashes on the screen. It is the

SOLAR SPECTRUM,

one of the most impressive visions ever seen by the eye of man, and is now known to be one of the most valuable of human possessions. This separation by inclined surfaces of a transmitting medium is termed dispersion, or separation of all the different wave lengths, the shortest waves—violet sensation—being bent aside, dispersed or removed to the greatest distance from the original straight line—the incident pencil—while long waves—red—are turned aside the least, with every other light wave between, the phenomenon being classed under the head of different refrangibility, or of varying rates of refraction, for dispersion



Cut 4. Dispersion of Light by Medium with its Inclined Sides—a Prism.

is not a physical fact in nature by itself, it being merely refraction. Since 1859, when Kirchhoff laid the foundation of modern spectroscopy, many of the most refined intellects of the world have studied incessantly the properties of this glorious band of colors. Indeed, only one line of research ever undertaken by man has exceeded it in intensity of thought—the calculus. Today there stands a majestic science, profound in its conclusions, far-reaching in its determinations, approaching sublimity in its deductions regarding the composition, construction and potential of the universe.

It is spectrum analysis. Let its study be continued.

II.

SPECTRUM ANALYSIS.

By the radiant light of the universal magnetic ocean, electric waves bind the cosmos together."—Veil of Isis, Vol. I, p. 282.

The reason why the colored band—the spectrum—is so valuable is that in it the waves are separated. Each length of oscillation is by itself and in a state suitable for measuring. Also the properties of each wave can be studied in their reactions on each other, and what is of great importance, the action of each kind of vibration on gross matter. Our lives and existence on earth depend entirely on these waves, also the only knowledge so far secured regarding the universe and the earth's place and man's place therein has come from three centuries of study of these tiny undulations. Waves therefore constitute a fundamental fact in nature, and should be studied by all who have the slightest regard for nature and her works. Every operation in the natural world round about is carried on by the most rigid and inexorable law.

LAW I.

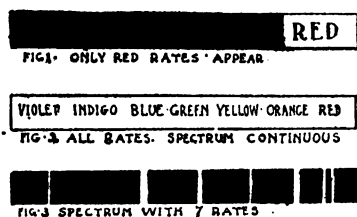
All solids, liquids and gases, under great pressure, project continuous spectra when incandescent.

This is one cornerstone in that majestic edifice, spectrum analysis.

BUILDING UP A SPECTRUM.

In cut 4, stop the clock of the heliostat and place a hot iron in front of the mirror, between it and the prism. Hold the hand near the iron, heat is the sensation imparted by the black mass. It is at once known that the iron is emitting waves. They are invisible, being too long and too slow in rate of vibration to act on the retinal nerves. Heat the iron hotter; watch closely and dull red will appear.

Increase the heat; all shades of red will develop, from dull to bright. Millions of different waves differing in lengths and rates will be seen. Reflect the rays through the prism, look on



Cut 5. Three Spectra.

the white screen on the other side, and figure 1, cut 5, will flash out. A band of red light will be seen extending from deep to bright red. This is because it emits only red rays; not being hot enough—*i. e.*, its internal particles do not oscillate fast enough to send forth any other lengths of waves. It is said that the metal is "red-hot."

For deep dark red, one inch contains 33,000 waves, and for deep low musical notes in a piano, vibrating 32 times per second, the wave length is thirty-five feet. So one deep bass wave from an organ is 13,860,000 times longer than a bass wave of light called red.

Heat the iron still hotter, it begins to lose its red color and becomes white. Look at the screen, then figure 2, cut 5, will be seen. It is a continuous spectrum, continuous because all wave lengths, all rates, are present. And these rates of vibrations are colors. For color in light is pitch in sound. Still increase the heat of the iron, it becomes a liquid, but the liquid is still white; it emits every possible rate, and the band of color is still complete but brighter than before, because the liquid iron is whiter than solid. But, during all this time, great events are happening outside the visible spectrum beyond the violet, in that mysterious region called the ultra-violet, now being explored with feverish anxiety by physicists to find more invisible rates in waves, and they are being discovered almost daily. The oscillating particles of iron set vibrating by the heat, beat so rapidly that the eye cannot follow the short waves sent out, for the invariable product of swings of particles is waves set up inside and surrounding every particle of matter in nature. For the shortest violet wave just within range of acute eyes, before final extinction in the invisible ultra-violet, has length such that 61,000 are within one inch. And the highest musical sound caused by a piano wire oscillating 4,000 times per second is conveyed by a wave three and one-third inches long.

Some can hear sound when the wave length is four-tenths of an inch in length, but it is not music—merely a very shrill sound. Thus, all sound waves are exceedingly long compared with light waves.

HARMONIES IN NATURE.

A continuous spectrum is, therefore, comparable to the keyboard of an organ, with every key open, the bellows being in constant action, the bellows corresponding to the continuous shining of the sun, or other source of white light. For the organ issues every musical note, and the continuous spectrum is made

up of every harmonic (musical) light—else it would not have been emitted by a white source. And this is why the musical is called the color or chromatic scale. Harmonics lie deep in nature, and their study has developed into a vast complex and mathematical science. But before the dark mass of iron became endowed with the swings or excursions to and fro of its particles rapid enough to emit dull red, it was at work in an invisible region beyond the red in issuing long, slow, heat waves, all too long and too slow to have effect on the retinal nerves.

But that marvel, the bolometer, contains a platinum nerve of exceeding delicacy and this detects the long waves far and away beyond the limits of the slowest red. The fast short waves beyond the most rapid violet are detected by the fluoroscope by slowing down rates and changing lengths, while the gelatine-bromide plates clutch the waves in space by the million and holds their energy fast in particles of silver. And the rapid and slow invisible portions of the spectrum are at present explored to about sixteen times the length of the visible, thirteen times in the ultra-violet and three times in the infra-red. So human nerves are not as sensitive as might be supposed, for platinum and silver are both more sensitive.

Now by a complex process, heat the liquid iron hotter than ever, turn it to gas and confine it if possible like vapor of water in a boiler, and look again upon its spectrum projected by prism on screen, behold! it is continuous still, for white hot gas emits every color, or rather every rate as well as white hot liquids and solids. This is as might be expected, for the source of every color is white. This, therefore, is a repetition of Law I. Now, after the terrific heat is in full activity, after the iron particles have been by it endowed with repulsion sufficient to tear them apart, forming a true gas, then release the pressure. At once the iron particles fly to immense distances apart—compared with their diameters, and swing to and fro with inconceivable rates,

in paths termed their own free paths of oscillation. But when all pressure is removed, so that the gas can expand and have plenty of room for its particles to make their own unconfined vibration, a marvelous thing happens; an action occurs that filled the minds of all physicists with admiration, wrought mighty changes in human concept of the structure of nature, enlarged the shoreless sea of knowledge, and inspired all who studied these things with enlarged ideas of the laws and magnitude of the sidereal universe. At the instant in which the particles of iron or any other phase of matter are allowed to vibrate at their own rate a new and mighty law takes effect.

LAW II.

All phases of matter, when vibrating at their own rate, project discontinuous or bright line spectra, no two sets of lines being alike.

This is another cornerstone upon which stands the temple of nature. When the iron gas is vibrating in fervent heat the appearance on the screen is shown in figure 3, cut 5, where all continuity in the spectrum has vanished, a series of bright lines alone remains. All the rest of the band is now dark, no light wave appears save those making up the bright lines. And each phase of matter known as iron, zinc, tin, palladium, hydrogen, aluminum, thorium, strontium, thallium or any other, projects an entirely different set of lines from all the others. Each series falls in the same measured place in the spectrum.

These lines are the most valuable element of knowledge and their discovery and method of producing them was one of the most remarkable achievements of man. They make up the alphabet of the universe, and spell out messages from our own and other suns, and can be read by an expert as well as the Morse dots and dashes in the telegraphic code. So now the current life events of the sidereal hosts in space are being read daily like a

newspaper, and not only read but recorded for future generations of men by that other marvel the spectro-camera.

The long dark band to the left of the red in figure 1, cut 5, need not have been drawn; its place is to show where the continuous belt of colors would have been had the light source been white, as in figure 2. The bright lines in figure 3, said to represent the iron spectrum, is tentative, for iron casts about 480 lines. So far no instruments have been mentioned save a hole in a shutter, dark room, prism and screen. The spectroscope itself must now be taken apart, each piece photographed and presented for study.

III.

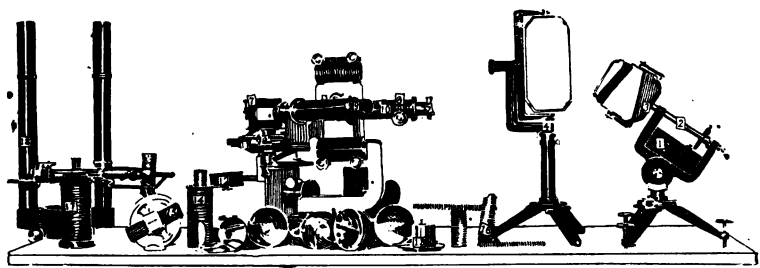
THE SPECTROSCOPE.

"Arise! the breath of our life has come! The darkness has fled. Light advances—pathway of the sun."—Rig Veda, I-113. Muir's Translation.

Since the corpuscles of every phase of matter when oscillating at their own rate traverse without hindrance their own free paths, in which case they must be separated (exist in a gaseous form), set up disturbances which are known as light, and project bright lines in their spectra, complex instruments must be had to analyze these emanations. The mechanism is called the spectroscope—to view the spectrum. In the beginning of this comprehensive study, the spectroscope was a simple instrument, but now after half a century of added improvement, has become one of the most intricate and delicate known to science. Indeed it must be, since its work is to tell what the universe is made of.

In cut 6, some of the complex spectroscopic apparatus in the Lowe Observatory is on display. The instrument to the right marked 1, 2, 3, is the heliostat (sun stand still). It is outside the observatory in full sunshine; (1) is the clock which turns the axis (2) and the large mirror (3) in a direction opposite to the direction of rotation of the earth. The sun shines on the mirror (3) and this throws a broad band of light from the sun into the laboratory through an open window. The beam of

light remains in one position in the room all day if required, the effect being as though the sun remained stationary. The axis (2) must be parallel to the axis of the earth, and exactly in the meridian, else the pencil of light would wobble around the central line. To make the axis of the heliostat parallel to that of the earth, it must be elevated above the horizon as many degrees as the heliostat is removed from the equator of the earth—that is, the elevation must equal the latitude. It therefore points to the pole of the heavens. This heliostat was a gift from those eminent ladies, the Misses Jennie M. and Matilda H. Smith,



Cut 6. Spectroscopic Instruments in Lowe Observatory.

of Allegheny, Pa. They devote their lives to the encouragement of science. Without this heliostat the complex spectroscope would remain idle and useless in the laboratory.

The ray of light passes into the narrow slit of the spectroscope (5). This is an opening between accurate metallic jaws, whose width is variable. Thus when it is desired to see the Fraunhofer lines in the solar spectrum, the opening is narrowed to the 500th part of an inch, or even less. The light emerging from the slit is three-fourths of an inch high, for the slit in sun work is vertical, and the 1-500th of an inch wide. It passes through the collimator (tube 6) and falls on a convex lens behind

8, and not shown in the cut. This lens casts an exact image of the slit upon the diffraction grating (7). This grating is an absolutely flat piece of polished speculum metal. It has been ruled with an exceedingly small diamond point, with lines 14,438 to one inch. The space shown white in 7 is the ruled surface and is $1\frac{7}{8}$ by $1\frac{3}{8}$ inches, and therefore contains 27,073 lines, grooves cut in the metal, and as many elevations of metal between. These elevations and depressions cause incident light to leave the grating by reflection in odd multiples of half wavelengths; that is, when the light is reflected away from the ruled surface it is in a state of interference, the waves are not in unison, crests and hollows, and crests and crests, interfere, and when white light makes interference darkness or colors occur.

In the diffraction grating no darkness appears, but a glorious band of colors is always seen when sunlight is coming in at the slit. It is the most beautiful vision that the eye of man has looked upon. It is none other than the solar spectrum. Diffract means to break; the white light is broken up into an infinite number of different rates of vibration—that is, colors. And color in light is comparable to pitch in sound. But when waves of light beat at their own rate, without obstruction from others, they not only appear under different colors, but each tint takes on its own direction, no two colors being seen coming from the same direction.

Hence the thin slit one five-hundredth of an inch wide, since it contains every rate, is widened into a long narrow band three-fourths of an inch high, filled with every color.

The band leaves the grating by reflection and falls on the convex lens (8), in the grating end of the telescope, (8, 9). At 9 is another lens called an eyepiece, not shown in cut 6, since it is now in the hands of Brashear, Allegheny, Pa., to be fitted into a new spectograph now building. Lens 8 forms a brilliant image of the band or spectrum on lens 9, and to an eye placed at 9

there is revealed a magnified band of innumerable colors, long, brilliant and marvelous in what it means.

But of inconceivably more importance than beauty or color, the Fraunhofer lines stand out in their majesty. There are more than 8,000 black lines, crossing the spectrum at right angles. Some are thin as a spider web, and others from ten to a thousand times wider. They appear in all parts of the spectrum, from the longest red to the shortest violet undulation. Their discovery and translation is the chief event that has occurred on the earth within the period of written history.

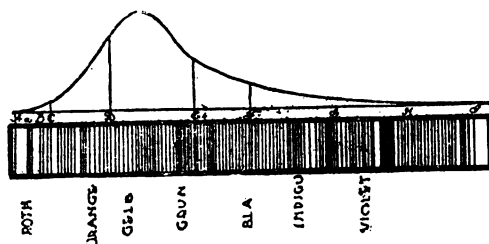
About A. D. 1600 Kepler placed a prism in a beam of sunlight and saw a solar spectrum—the first recorded in the annals of science. A century later Newton admitted light through a round hole in a shutter into a dark room, placed a prism in the beam and obtained a clearer band than Kepler's. At the end of another century, in 1802, Wollaston did what Newton performed, only he admitted the light through a narrow slit, and his was the first mortal eye to see the spectrum crossed by a few black lines. Twelve years later, Fraunhofer let in light through a slit, as did Wollaston, but happened to look at the spectrum with a small telescope—an act that changed the course of science for all time and gave rise to the chief study that ever actuated the human brain—spectrum analysis.

IV.

FRAUNHOFER'S SPECTRUM.

"The bright one, whose powers are unequaled. The oracle, the high ruler, the southern sun."—Inscription on obelisk in Palace of Nimrud. Primeval Assyrian. (Cuneiform) Talbot's Trans.

Fraunhofer, with the little telescope, discovered hundreds of fine, black lines crossing the spectrum of the sun at right angles to its length. In cut 7 is shown his original and now historic spectrum of the sun, in which he mapped 576 black lines.



Cut 7. Fraunhofer's Original Spectrum.

Universal interest was at once awakened; and it is a fact deep in psychology that the leading minds in Europe began intense study and labored on the spectrum from 1814 to 1859, as if impelled by resistless desire to find the cause of the mysterious lines. All realized that a magnificent law of nature was concealed in the spectral bands, but none could read the hand-writing.

Neither Herschel, Young, Bunsen, Brewster and hundreds of others, nor indeed Fraunhofer, could approach solution of the cipher dispatch from the sun. For forty-five years a most exciting search was made—one of the most remarkable in the history of man—in quest of a mighty law. Finally Kirchhoff stood up, in 1859, and announced to a waiting world the key that would translate the alphabet of nature—the strange glyphs in which she had for ages striven to open up communication with human beings.

Kirchhoff unlocked the gate of a labyrinth more inscrutable than that of the Egyptians; the great doors swung on their rusty hinges, hundreds of barriers vanished as if by magic, and he peered into the long dark corridors, hermetically sealed, until he found the key.

The discovery of the origin of the Fraunhofer lines is equal in importance to that of the law of gravity, for the law of gravitation “weighs” the universe, and the law of Kirchhoff tells what it is made of.

BUILDING UP A SPECTROSCOPE.

In the cut published in the third paper all parts are shown assembled into a complete instrument. Each part must be examined separately to gain an idea of this most powerful weapon in the hands of man for his ultimate conquest of nature.

In cut 8, figure 5, is shown the slit of a modern spectroscope as made by Brashear. It is unscrewed from the end of the collimator tube. In the cut the slit is opened hundreds of times wider than when in use, so that it may be seen. The light direct from the sun is sent by the revolving mirror of the heliostat (cut 6) into the narrow opening. When making an examination of an exquisite Fraunhofer line, whose thickness is comparable with that of a spider web, the distance between the jaws ranges from the one-five-hundredth to the one-thousandth part of an inch, invisible almost to the unaided eye. But the powerful light of the



Cut 8. Fig. 2, 3, Electric Lantern for Micrometer Illumination; Fig. 5, Slit of Spectroscope; Fig. 8, Collimator Lens; Fig. 16, Searchlight Carbon—3,000,000 Candle power; Fig. 17, Two ordinary City Arc Light Carbons.

sun finds a way through it and falls on the convex lens (figure 8) in cut 8, which was detached from the opposite end of the collimating tube.

The work of this lens is to project an image of the slit upon the diffraction grating. The slit is in what is called the principal focus of the lens. When any object is in this point, rays from it emerge parallel from the lens, the effect being the same as though the object (the slit in this case) were at an infinite distance.

In the Lowe spectroscope the slit is five-eighths of an inch high and of any width desired. The jaws of the slit are moved toward or away from each other by screws, and the edges are as straight as can be made by human hands. If not, the lines in the spectrum would be distorted so they could not be measured with the micrometer. The slit, therefore, is a very important part of the spectroscope and corresponds to the narrow aperture

in the shutter of a darkened window, employed by the early physicists in their gropings after a secret of nature, only found at the end of 250 years incessant study.

The collimator is simply a metal tube fourteen inches long, with slit at one end and projecting lens at the other, the sole use of the combine being to cast an accurate and brilliantly lighted image of the slit upon the excessively fine rulings of the grating. This bright image is not magnified—it is still five eighths of an inch high and of the same width as the opening between the jaws.

PHASES OF MATTER AND THEIR ANALYSIS.

So far, these notes have arrived at the cardinal fact in nature that the solar spectrum is crossed by thousands of black lines, scattered here and there in the midst of gorgeous colors. A devious course was traversed by the human mind before they could be translated. For lines cast in the spectra of every phase of matter known, are bright, highly colored and not black.

Before attacking the mighty problem of black lines in the spectrum of the sun, the bright lines must be understood.

If you hand anything to a chemist for analysis, he will probably dissolve it either in acid, water or other solvent, and subject the mass to the action of reagents. But the spectroscopist at once subjects the substance to terrific heat, passes the light from the resulting incandescent gas through the slit and collimating lens and allows it to fall on the grating.

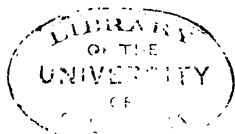
Each phase of matter when corpuscles are torn apart and separated far enough to allow them to oscillate, will vibrate at its own definite rate. Each oscillation of a corpuscle will cause another to swing, and another, the motion being a wave movement. But each wave strikes its own place in the spectrum, and sets of similar waves form the bright spectrum lines, due entirely to wave lengths and rates of oscillation. The best way to make

corpuscles of metals swing at their own rate is to force them apart by the intense heat of the electric arc.

Figure 16, cut 8, is the positive carbon just as it was taken out of the circuit shortly after having been used in the 3,000,000 candle power searchlight on Echo Mountain. The crater is shown scooped out deep into the soft core of the carbon. In use the negative carbon is above this, separated by an air space, through which the electric arc plays with its appalling force and heat. Place the carbon points a few inches from the slit, put a chunk of metal or metallic salt or compound, flint, silicious compounds, rubies, diamond or any refractory substance whatever into the crater and turn on the current of electricity. At once the metal or anything else is turned white hot, and then to a still hotter gas, which fills all the space between the carbon point above and crater below. But, at the instant when the gas becomes hotter than white, that is, when each corpuscle is torn away from all the others, each vibrates at its own rate, and a set of brilliant lines is seen on the grating, no two sets being alike.

Each set is one letter in nature's alphabet. Their positions are measured with accuracy, and waves sent from iron, titanium, helium, or any other phase always fall in their own invariable places. This is the basis of spectrum analysis.

In cut 8, 17 is an ordinary city arc light carbon, with another leaning against it with wires attached. And these as well as still smaller are used in spectroscopy, they having craters large and hot enough to vaporize metals. Under the figure 5, half covering the slit is a total reflection prism, and light falling on its base is reflected by the hypotenuse into the slit. Thus two sets of lines from two metals, or from one metal and the sun can be projected on the grating ready for analysis and comparison. The tube 2-3 is an electric lantern to illuminate the spider webs in the spectro-micrometer, and will be explained when that instrument is presented.



V.

"When thou seest the holy and sacred fire devoid of form, burning and flying everywhere into the depths of the universe, listen to the voice of fire."—Plethon, *Iranic Literature*.

In cut 9 a rough drawing is shown of the parts of the spectroscope that receive light and prepare it for analysis. To the right is the upper part of the axis of the heliostat with its mirror, which is revolving from east to west to counteract the rotation of the earth. Beams of light are falling upon it from the sun and the brilliant mirror reflects them through the slit, 1-1000th of an inch in width, and projects the rays upon the lens in the opposite end of the tube. The lens forms a clear cut image of the open slit upon the ruled surface of the diffraction grating,



Cut. 9. Mirror of Heliostat, Collimator and Diffraction Grating.

which image is the same size as the slit, not being magnified by the convex lens, because the slit is in its principal focus. After more than a century of ever-increasing mechanical accuracy, at last a perfect image of a slit is had.

It might be thought an easy matter to make an opening with sides exactly parallel and straight, but to make a straight line is a task of great difficulty. The grating is a flat piece of speculum metal, and to make a flat surface is far more trying to mechanics than to make a straight edge. The ruled surface is 11-2x17-8 inches and is ruled 14,438 to the inch. To rule it required several days and nights incessant work in a constant temperature room.



Cut 10. Grating. Showing Incident Rays, and Wave Fronts after Diffraction and Reflection.

The metal plate is three-eighths of an inch thick, and in figure 7, cut 10, is seen lying on its back, showing the grooves as they were cut with a diamond point. The grating is superior to the prism in the fact that it makes a normal spectrum. Each wave falls into its proper place, which is not true of the prismatic spectrum.



Cut 10A. Fig. 7 the Diffraction Grating; Fig. 13, Prism.

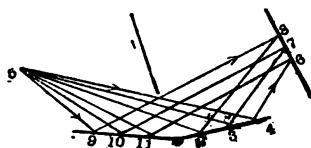
The diffraction grating is one of the most valuable of human possessions. It has expanded knowledge more, perhaps, than any one discovery, unless the calculus may be classed with it in power. So numerous and important are the record breaking

discoveries made with the grating that its action on radiation must be thoroughly understood.

DIFFRACTION AND INTERFERENCE.

These will be treated as identical here; they are cardinal facts in nature, and their study has taxed the resources of physicists and mathematicians since Newton produced diffraction rings. Light is a wave motion in the corpuscles discovered by Professor J. J. Thompson. All along a hypothetical ether was postulated to be the medium of transmission of all radiant energy—but Thompson's negative corpuscles, saturating the universe, meets every requirement of the electro-magnetic theory of radiation, due to Maxwell.

All radiant energy is conveyed by means of waves in corpuscles, but it is known that waves interfere with each other. If two waves exactly alike interfere, both are totally destroyed.



Cut 11. Fresnel's Mirrors.

Drop two stones in water at some distance apart, waves will expand in circles; in a short time the two circles will collide; but if two similar waves in opposite phase meet, the water will be at rest and a cork floating thereon will not oscillate. If two water waves interfere, rest succeeds; if two light waves, darkness

Stillness in water corresponds to darkness in the midst of light, for light added to light may produce darkness.

All this can be seen in cut 11, due to Fresnel, where 9, 10, 11—2, 3, 4 are on the surfaces of two plane mirrors hinged at the centre. Their reflecting surfaces are nearly in the same

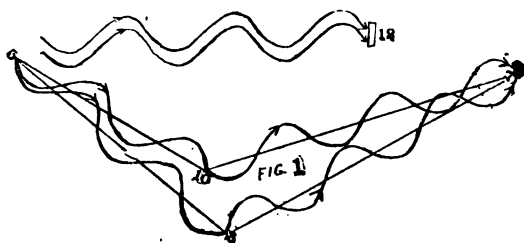
straight line, the inclination angle being but little less than 180 degrees. At 5, is the radiant, a brilliant point or slit, while 6, 7, 8, is a white screen, and 1 is a curtain so that light from 5 will not go direct to 6, 8, and obscure the light from the mirrors. Its use leads to startling results. Let light of any one wave-length—say blue—radiate from 5, strike both mirrors as shown and be reflected to the white card 6, 8. One point on each mirror as 9 and 2 may be chosen so that the ray 5, 9 added to 9, 8, shall equal in length the ray 5, 2 plus 2, 8. Then a bright spot of blue light will appear at 8. This is because the waves leave 5 and arrive at 8 in the same phase. But if the ray 5, 10, plus 10, 7, and 5, 3, plus 3, 7, differ by half a wave-length, a dark spot is seen at 7. Blue waves meet at unlike phase and destroy oscillation. The hollow of one comes opposite to the crest of another, the motion of corpuscles is quenched, the waves interfere and both are destroyed.

Thus the undulatory theory of light was proven, for matter added to matter cannot destroy both—light is therefore not matter. And there will be alternate bright and dark spaces on either side of 6 and 8, cut 11. If the radiant 5, gives white light, there will be no dark spots, but every possible color will take their places and the cause must be known or the formation of an interference or diffraction spectrum cannot be comprehended and the secret processes of nature remain undiscovered forever.

CAUSES OF INTERFERENCE SPECTRA.

Figure 1, cut 12, is an enlarged view of the rays 5, 10, 7 and 5, 3, 7, in cut 11. Ray 5, 10, 7, in cut 12, shows 5 waves, and 5, 3, 7, $5\frac{1}{2}$. They interfere and destroy each other's motion, hence a dark spot appears at 7. The corpuscles at 7 are actuated by equal motions in opposite directions. They remain at rest for the motions are in directions of the arrows. The darkness appears if one kind of light, as violet, is used, but if white light

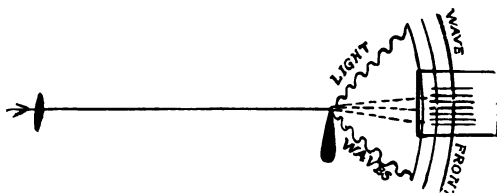
is reflected, then any color may appear at 7, which color depends on the angle of the light, incident on the mirrors. For the next ray to 5, 10, 7 and 5, 3, 7 might not differ by half a wave-length, and not interfere, and therefore fall on the vacant



Cut 12. Enlarged Rays from Cut 11.

space filling it with its own color and so for all the countless millions of waves of white light that fall on the mirrors. Some will be quenched and some augment, and build up a long colored band, a continuous spectrum.

Thus in figure 2, cut 12, two rays are shown in harmonic oscillation, the arrowheads at the end point in the same direction. and an illuminated band is seen at 12. The spectrum there-



Cut 13. Diffracting Light over edge of razor.

fore is not as bright as the radiant, for so many waves are destroyed, the spectrum from the sun is not bright, it is easy on the eyes and beautiful.

DIFFRACTION.

In cut 13, the diffraction or breaking of light is shown where light from the lens is seen diverging to the screen, but half is cut off by the edge of a razor or sharp knife. When the primary wave hits the edge of the knife, a new set of waves is set up on the particles of metal, and they radiate light, some above and some below, as seen on the screen. One circular wave front is shown moving away from one rough saw-tooth on the edge of the razor, and two in the original wave series. These and millions more interfere and break up the light, for diffraction is interference. If the light used is of one kind, as orange, black spaces and orange will appear on screen. If white light, the screen shows colored fringes in order of wave lengths. But the razor's edge corresponds to the elevation of metal between two grooves shown in the vertical grating, cut 9, and in figure 7, 10A. And all the inclined sides of the grooves correspond to the inclined mirrors, cut 11. And this is the philosophy of the grating in the most primitive form, where if it were being treated mathematically, one-tenth of the space would be required that is taken by this multitude of words. Cut 10 shows four waves diffracted from the elevations, all interfering on their wave fronts, and two coinciding in phase reflected from the sides of the depressions. This is the making of that priceless object, a spectrum.

Refraction is seen in all its glory in the diamond, and ordinarily in the prismatic pendants from chandeliers, gas fixtures, and lamps, and in cut glass.

Diffraction is on display in the peacock's feathers, on the thin striae of shells, and on films of oil on water. They both cause interference and colors. Without them the earth and all things therein would lose their beauty.

VI.

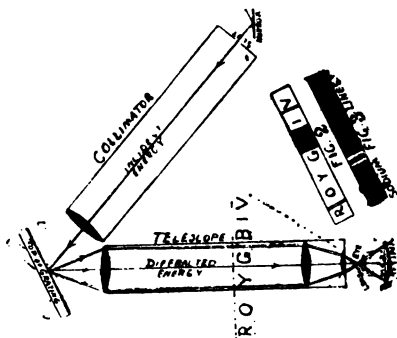
ANALYSIS OF ENERGY BY MEANS OF THE SPECTRUM.

"It appears to me that what we call the principle of heat is immortal—that it knows all, sees all, hears all, both in the past and in the future. At the time when all was confusion the greater part of this principle rose to the circumference of the universe. It is this that the ancients have called ether."—Hippocrates.

All the preceding chapters have led to the projection of a brightly illuminated image of the slit on the grating. Energy falling on this thin band is worthy of attention of the highest type of intellect that has appeared.

The slit and its resultant image are filled with countless quadrillions of waves, mixed in apparently hopeless confusion. To make use of the wonderful power of the grating, the image must be viewed with a telescope inclined to its surface. If not inclined, then dispersion of the energy into separate waves would not be seen and analysis could not be made. Each wave length must be examined by itself. And so small is the image of the slit and so narrow the spectral band that it must be magnified. Thus the one lens of the collimator forms an image without enlargement; the lenses of the telescope magnify. The result is a long belt of the most gorgeous colors from short-violet to long-red waves, and if white light enters the slit the spectrum is

continuous—without break—that is, every color between V and R is present. For if one tint-rate was missing, a black line—an image of the slit—would cross the band at right angles. This must be, for all the waves are separated by the rulings on the grating, and there are none to fill their places. This is a cornerstone in spectroscopy.



Cut 14.

This can be understood from cut 14, where the rough outlines of a spectroscope are shown as seen by a person standing on a chair and looking straight down. A pencil of energy from the sun or any substance being analyzed by means of the energy it radiates, is seen reflected from the mirror through the slit and lens of the collimator and falling on the grating. The top edge of the grating is shown. It stands on a revolving table and can be turned through any angle as shown by the dotted lines. The edges of the table are ruled into 360 degrees and parts of a degree which are still closer read by vernier and microscope. The angle the grating makes with the incident ray can be measured with accuracy. The elevations and depression on the grating diffract—break up—and disperse—separate—all waves according to their lengths, sort them out by themselves and reflect them all upon the object-glass of the view telescope.

The telescope turns in all directions around the center of the grating—that is, about the image of the slit as a center, and these angles can be measured with precision. The angles of deviation are of great use, for finding by trigonometrical formulas, the lengths of the waves. These waves can be measured with extreme accuracy. the objective of the telescope renders the incident diverging rays parallel and projects the cylinder upon the fieldglass of the eye piece as shown. This lens makes the parallel rays converge and fall on the eye lens, which further converges and causes them to cross just in front of the lens in the eye, which projects an image of the spectrum on the retina as drawn; but the observer thinks the image is far from the eye in space near the middle of the telescope shown in the dotted spectrum and the letters V I B G Y O R.

The size of this imaginary spectrum depends on the angle made where the rays cross between the glass lens and lens in the eye. For the side of the retina marked A, sees red light in the direction R; and the side of the retina marked R, sees violet light in the direction V, and it is a principle in optics that the observer imagines an object to be in the direction in which rays fall on the retina. If white light enters the slit, the eye will see all possible colors from R to V, but if any waves are missing, a black line will be seen, as in figure 2, cut 14, where all the blue waves, two red and one violet, are absent.

All phases of matter, when hot enough for corpuscles to have room sufficient in which to oscillate at their own rate, project spectra consisting of bright lines only, no two phases being able to cast identical sets of lines.

This is one of the chief facts known. Heat sodium, for instance, hot enough, either by a Bunsen burner, by the electric arc or spark, and hold it close to the slit, and the conditions represented in cut 14, figure 3, will be seen. Two bright lines in the yellow flash out, and all other portions of the spectrum will be

black. This is because the metal sodium is unable to vibrate in more than two rates, and cannot set up any other waves, hence their places must be dark. So far, more than 80 conditions in which matter exists, have been found, and their bright lines carefully measured and mapped. These lines and bands are the natural alphabet. He who desires to know of the universe must read.

There are 42,175 long sodium waves and 43,078 short in one inch. The rate of the long waves is 495 million million, and of the short 507 million million oscillations per second. This is known to be true, and may be demonstrated by analysis, either of the energy, or the sodium as one pleases to call it. The Roentgen or X-rays are much more rapid.

The metal sodium is the basis of common salt. The ocean spray is evaporated in the air, leaving minute particles of salt in suspension, filling the atmosphere around the globe. So delicate is spectrum analysis that it is almost impossible to be rid of the two yellow sodium lines, while making analysis of other metals. Bunsen found that the one 14-millionth of a milligram of sodium projected the well-known yellow lines. The rustling of a paper or movement of the hand through the air arouses a hurricane of the particles, these fall into the source of heat, are instantly torn into corpuscles hundreds of millions of times smaller, and these set up waves that enter the slit. Lithium vibrates with two rates, one yellow and the other orange. Iron beats with about 480 different velocities, while the metal thallium has but one rate.

IDENTIFYING THE LINES.

Each line cast by any state of matter must be capable of being identified by inspection. The distances between the lines, the widths of the lines themselves, and their positions in the spectrum, are invariable for the same purity, temperature, pressure and grating.

Widths, spaces and positions are measured by means of a micrometer placed in the eye-piece. This is an instrument composed of two spider webs crossed like an X and stretched across a moveable frame in the field of view; that is, they are in front of the spectrum and can be moved by rotating the screw so they will bisect any line or space and measure all with an accuracy almost past belief. It has been agreed to by spectroscopists throughout the world to adopt the universal standard of ten-millionths of a millimeter in which to express wave-lengths of radiant energy. The spider lines must be illuminated by a side light to render them visible under all circumstances. For they are so thin that they are not at all times visible when in front of the colors of the spectrum.

This is the office of the electric lantern, 2, 3, cut 8.



Cut 15. Spectroscope in Lowe Observatory.

In cut 15, is shown the complete spectroscope in the Lowe observatory. The grating is shown between the objectives of the collimator and view telescope, while the micrometer is seen to the left, attached to the eye-piece of the telescope. The slit is at the right, and the edge of the circular ruled turntable is shown under the grating in the center. The entire instrument stands on

three leveling screws to centre the slit on the mirror of the heliostat in the bright sunshine outside. The ruled screw-head is not seen in the cut, being on the opposite side of the tube; but the window of the micrometer is seen on this side. The little tube attached to this side of the telescope is an electric lantern, in which is placed a minute (1 c. p.) incandescent bulb with wires leading to a battery cell. When the current is on, the light passes to a right-angled or total reflection prism in the other end of the tube, where it is reflected through the window pane shown, and strikes the webs in front of the eye. They look like minute fibers of glittering white and are clearly visible against any color behind them.

Each spectroscope must be made the subject of experiment until the value of one turn of the screw is found in ten-millionths of a millimeter, and is called the constant of the micrometer. One millimeter is very nearly equal to the 1-25th of an inch, and therefore it is with 25-millionths of an inch that the modern spectroscope deals. It is hoped that the word inch will disappear from scientific literature.

When any phase of matter casts a spectrum, it is better to let its light make a graph on a sensitive plate than to make a map by hand drawing. The natural writing is more accurate, and the lines can be measured with a measuring machine as well as by the web micrometer. Thus photography, that majestic science, is the constant companion and helper of the spectroscopist and astronomer.

In cut 15, the telescope and collimator are opened at a very wide angle to give a view of the grating, both objectives and the lantern. The spectroscope could not be used at so wide an angle; the telescope must be turned around. The slit is shown on the end of the collimator to the right. On the table below is a tube with lens in one end, which lens forms

an image of any luminous object on the slit, so any part of the image may be examined instead of the whole object.

This, then, is an analyzing spectroscope, where the slit without the lens between it and the object would be an integrating instrument. On the table to the left is a different kind of a slit from that of the collimator. It is for analysis of energy direct from the sun and will be treated in Part II, on astronomical spectroscopy.

PART II.

VII.

ASTRONOMICAL SPECTROSCOPY.

"Anaxagoras teaches that the ambient ether is of an igneous origin, and by the force of its gyratory motion it tears off blocks of stone, renders them incandescent, and transforms them into stars."—Plutarch.

The elementary notes I to VI inclusive, dealt with diffraction, inflection, and dispersion of energy into a spectrum. Rates were from 395 to 764 million million per second—commonly called light. It was shown that swings of corpuscles to and fro like a pendulum give rise to disturbances which are imparted to the next and next and so on with a speed in a straight line always of 186,000 miles per second in space, and with less velocity in transparent and refracting media. It was seen that white light is composed of an infinite number of different rates of swing—called colors, and that these vibrations could be sorted and placed by themselves by dispersing apparatus such as prisms and diffracting gratings. But when so separated it was found by a century of study that different phases in which matter exists could be detected by merely analysing the waves they set up. For each condition of matter when its corpuscles are vibrating at their own characteristic rates cause different sets of waves, varying in lengths, amplitudes and periods of oscillation.

All of the eighty or more modes of matter have been made to vibrate in front of the slit by heat, as from the electric arc between carbon terminals, in whose plus crater metals were placed,

which were at once vaporized, forcing corpuscles to undulate in their own free paths; or by the terrific heat of the stored up electric sparks through an air gap between terminals of metals under analysis and held before the slit. The current is passed through an induction coil, and if high potential is desired for the refractory metals, Leyden jars with air spaces are set up tandem in the secondary circuit of the coil, which turn the most obdurate metals to gas, and set the corpuscles into rapid pulsation, sending their own waves to slit, grating and spectrum. Also the heat of the oxy-hydrogen jets, gas jets, Bunsen jets, air and coal gas, as well as alcohol flames have been employed to set corpuscles swinging, the object of all being to get their energy in the spectral band—into a state of isolation for examination by themselves. The entire process is termed spectrum analysis, or spectro-chemistry.

But all this took place among familiar states of matter here on the earth. The whole three centuries of incessant work—even if every condition on the earth were analysed, would amount to little since the earth in space is smaller than one of Thomson's corpuscles in proportion to an ordinary room, and an "atom" of hydrogen—the smallest physical body known, is 1,000 times more massive than the corpuscle. So if men could not enlarge their sphere of action and get away from this terrestrial sphere—the entire labor of the human species from appearance here, would be exceeding small. Hence the whole subject of spectro-chemistry, with its extensive literature, with its record of arduous toil day and night, with incessant vigil of the tiny electric spark and smaller wave, with its days and months and years of incredible work and consummate skill of body and brain, the finest yet developed on the planet—all these and all the books, whose titles only fill a large volume, all must be passed here and that other branch of spectroscopy taken up, the astronomical.

So far bright lines only have been noticed, luminous as they

fell in their regular places fresh from hot, vibratory corpuscles. But in 1814 Fraunhofer looked at the solar spectrum with a telescope and saw "an infinite number of vertical lines, darker than the rest of the spectrum, and some of them appear entirely black." He mapped 576. (See his map in Fig. 4.) He died without knowing their cause. In 1822 Brewster put colored glasses between the sources of light and the slit. The entire spectrum disappeared except the waves having the same color as the glass. Herschel did the same with colored glass and also with colored liquids. They quenched all waves except those they emitted. If white light be passed through red glass the whole spectrum vanishes except red.

In making researches in absorption the physicist Brewster wrote: "The first object of my inquiries was to discover a general law of chemical analysis in which simple or compound bodies might be characterized by their action on different parts of the spectrum."

He said there must be absorption, but this mighty law he failed to see in all its clearness—to him it appeared in dim outline like a ship coming out of mist. The human mind was groping in darkness in presence of one of the chief mysteries of nature. This was in 1833. The black lines in the solar spectrum were absolutely inexplicable. Becquerel photographed these lines in 1842 and Draper in 1843.

About this time began one of the most extensive series of researches in the history of the world. Arduous and long continued. Every physicist knew that a magnificent law was hidden in the black solar lines.

PRODUCTION OF BLACK LINES BY EXPERIMENT.

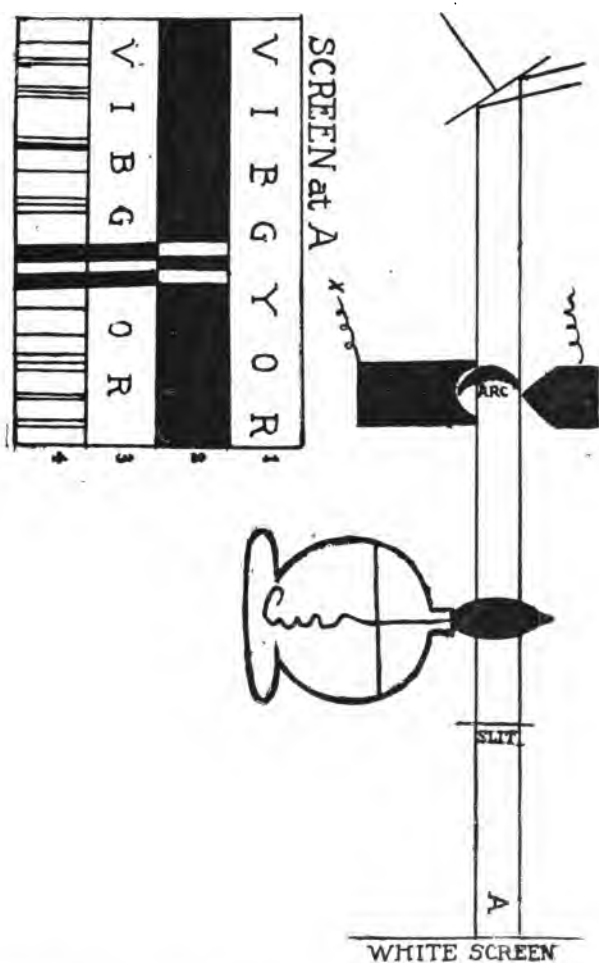
Spectroscopists began to imitate the sun. Foucault in 1849 projected white light through yellow sodium light in an electric arc and produced two black lines in the exact places of the two

yellow on a screen. For some reason this did not awaken the world, although it was the beginning of celestial chemistry. Men had to wait ten years until that eventful and auspicious day, October 27, 1859, when Kirchhoff's immortal work was read to the Academy in Berlin. Here are a few of his words:

"I formed a solar spectrum by projection, and allowed the solar rays concerned, before they fell on the slit, to pass through a powerful salt flame. If the sunlight were sufficiently reduced, there appeared in place of the two dark lines, D, two bright lines; if, on the other hand, its intensity surpassed a certain limit, the two dark lines, D, showed themselves in much greater distinctness than without the employment of the salt flame."

These words have the same relation to spectroscopy of the sun and stars that the Constitution has to people of the United States. They are fundamental, historic, wonderful.

The basic fact can be understood by means of Cut 16, where is shown a lamp burning alcohol which makes great heat with little light. The wick has been saturated with a solution of common salt and dried. The heat volatilizes the metal sodium, tearing its particles away from their union with chlorine. They vibrate at their own rate, and fill the entire flame with dense yellow light. If now this light be passed through the slit, two brilliant yellow lines are seen at A, and the remainder of the spectrum is dark, because sodium is unable to vibrate in more than two rates. Cut 16, Fig. 2. If strong white light concentrated into a beam be sent, say from an electric arc, through the flame, the bright yellow lines vanish and all the other parts of the spectrum reappear, except in the two places occupied by the bright lines which are now black. Fig. 3. And if instead of the electric light, sunlight be sent through the yellow flame, the two black lines already in the yellow region of the solar spectrum become blacker than before, Fig. 4.



Cut 16. Electric Carbons, Alcohol Flame, and Absorption Spectra.

If a piano wire tuned to say C, be stretched across the end of a long room, and many other wires all tuned to C be stretched somewhere near the other end of the room, with an observer standing behind them—then if the one distant string be set in vibration the listener will not hear it, but will hear the C note in all the wires near him. The many wires cut the waves of the one other out of space, and quench them by appropriating their energy to their own use. Sound any other wire near the one C wire, and the listener behind the screen of wires will hear any note whatever except C. The wires in the screen are unable to vibrate in any other rate than that required to sound C. So with the corpuscles of sodium—they are tuned to yellow with two rates and cannot oscillate at any others. Hence the yellow flame lets every other color rate through without hindrance and absorbs the yellow, producing black on the screen A.

In cut 16 the prism or grating is not drawn. Fig. 1 is a continuous spectrum as cast by the electric arc alone. Fig. 2 is that of sodium alone. Fig. 3, that of the electric white light shining through sodium yellow light. Fig. 4 is a minute portion of the spectrum of the sun near the sodium lines, showing others. But the two sodium lines always seen black in the sun, fall in the exact places occupied by the two bright lines of sodium.

LAW III.

All modes of matter when vibrating at their own rates absorb the same waves they are able to generate.—Kirchhoff.

The mystery of the sun is not yet explained.

VIII.

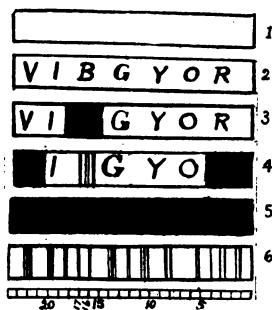
ABSORPTION.

"One nature delights in another; one nature overcomes another, one nature overrules another, and the whole of them are one."—Book of Stone, Temple of Memphis, Archaic Egyptian, Synesius copy.

The extinction of energy in space or its absorption and consequent disappearance in matter is a deep seated fact in Nature. The appropriation and selection of waves by matter and their eventual return to space constitute the life of the universe, the ebbing and flowing of cosmical tides. In treating of that minute fraction of the total and invariable quantity of energy, usually called light, it is well to recall that if matter quenches every light wave that penetrates below its surface, it is said to be jet black. A black object is seen merely from a small portion of the incident light reflected from its extreme outside inconceivably thin layer of particles. The processes taking place in the next layer destroys light so far as seeing it is concerned, and in the present state of science seems to be lost—falling on some bodies; but if the waves strike a growing plant they do work. They are said to be absorbed, and a green leaf absorbs all waves except the green, which are reflected, and a red rose absorbs all waves but red. Thus there is no color on earth—all colors are in the light.

Particular attention must be given to absorption in the spectrum of any light whatever. The subject is a mighty one, for by

this means only can the key to read the letters of the universe be found. Every absorption letter is made up of short vertical black lines in the spectrum of either our own or the multitudes of other suns in measureless wastes of space—that is, the stars (suns), are read by means of waves that are absent, waves that would have reached the earth as bright light had they not been cut out by some means, which is now the problem to be solved—the capital problem so far solved by man.



Cut 17. Six Spectra and Scale.

In cut 17 an attempt is again made to clear up the question of absorption, or destruction of wave motion. In Fig. 1 the paper appears white because white light falls upon it and is reflected without change. That is, the waves are not separated, but are mixed in confusion, and a jumble of all possible waves appears white. In 2 there is shown a continuous spectrum, all colors from red to violet are present. (It is difficult to explain spectroscopy without diagrams in colors.) The cause of this is the waves have been separated by a prism or grating; for when waves are dispersed colors appear, for each wave vibrates at its own speed, free from all others. In Fig. 3 blue is missing, black results, for



no other waves can fill that space; none but blue have such refrangibility and cannot be bent into that vacant region. Indigo and violet are refracted by a prism or diffracted by a grating too far to the left, and the other colors not far enough to fall where blue alone is able. In 4 violet and red are wanting and four waves of the green also. These attempted to pass through a gas that may have been invisible or transparent to all colors except green, or possibly they hit against a block of wood, both equally opaque. In 5 the entire spectrum has vanished, by their having endeavored to pass through an absorbing medium as black glass, or through a great thickness of clear glass or of water. At all events they are absent and black appears. In 6 a crude spectrum of the sun is shown with a few black lines only out of over 8,000 known. Since the spectrum did not fall on a surface able to quench all the waves, for many appear, and since a number of black lines are seen, the solar rays have surely traversed a gas having power to select, quench or absorb all the missing undulations whose normal spaces are occupied by black. The micrometer cannot be well shown here, so a rule is drawn at the bottom of the series of 6 spectra. A straight edge placed on the 16 in the rule will coincide with the black line in the green rates in 4, and likewise with ruling No. 17. Evidently there is no mode of matter in the sun whose corpuscles swing with these rates or the waves have been counteracted between the sun and earth. For under all circumstances these two lines fall at 16 and 17 on the rule with the same prism or grating.

Proof will be given in a note on solar chemistry that these states of matter really are incandescent in the sun and that the black lines are truly absorption spaces—images of the slit—black because these waves did not enter the narrow opening, being absent in those radiations reaching the earth from the sun, not sent, or, if emitted, absorbed.

IMITATING THE SOLAR FURNACE.

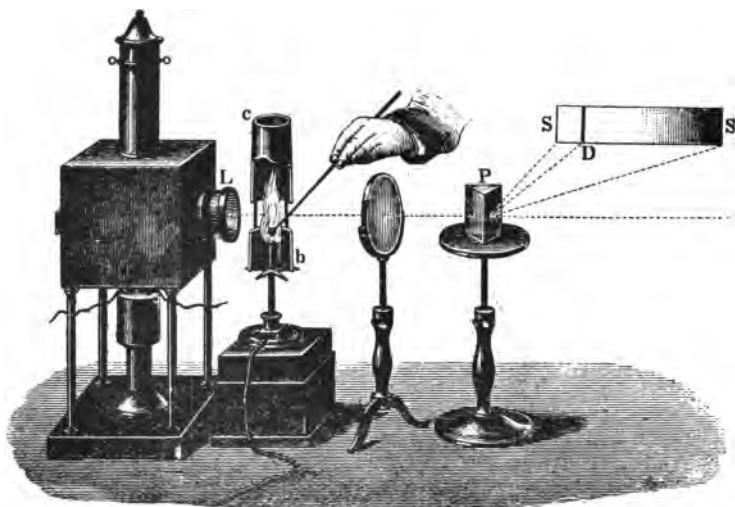
In cut 18 is seen an instantaneous photograph of two arc light carbons immediately after the current was shut off. The crater in the plus or lower carbon is still white hot, the cavity scooped



Cut 18. Graph of Arc Light Carbons.

out by the flowing electricity and its terrific heat, for carbon is the most difficult of all modes to melt or vaporize. Now, if the proper phase of substance is thrown into this crater and the resulting waves be passed through the slit, the two lines 16 and 17 in Fig. 6, in cut 17, can be exactly matched, if the two spectra are

placed side by side—that is, the lines will be end to end as in cut 16. This is the same as saying that the two black lines in the green corresponding will be filled with green light in Fig. 4, in cut 17. In the present state of spectroscopy part of the dark lines in the spectrum of the sun can be filled up with their proper light in the laboratory, but not all. There are black lines not yet accounted for—that is, no mode of matter yet discovered on the



Cut 19. Lockyer's Electric Arc and Projection Spectra.

earth will set up the right waves to fall in these vacant places. At present a most exhaustive search is constantly being made to find phases that will oscillate at the solar rates and fill the lines with bright light. Modes have been found in the sun first, and afterward detected here on earth. These will be given in a note on the chemistry of the sun.

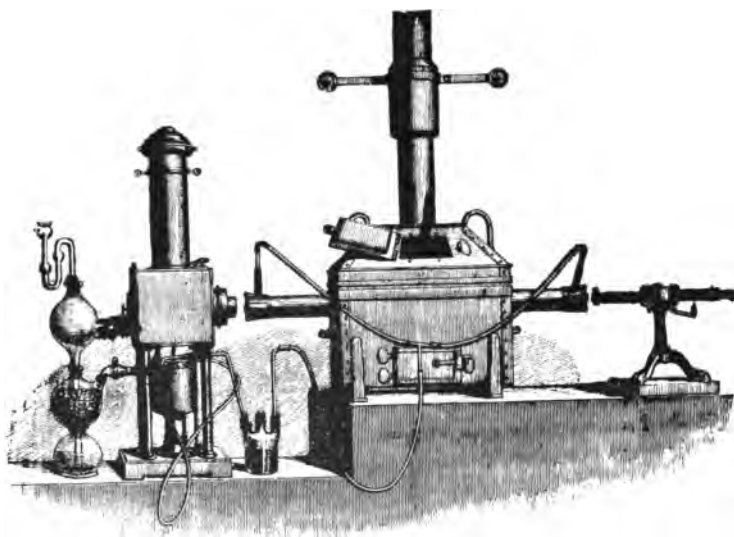
Cut 19 is an outfit from Lockyer's studies. In the left stands an electric lantern containing the two carbons in cut 18.

Wires enter the bottom. To the right is a lens L. Next is a Bunsen burner burning city gas mixed with air coming in alongside of the gas below. The spectroscopist is holding a platinum spoon in the hot but dim flame—high heat, low light; the waves are too long for light. The heat is not great enough to melt the platinum, but will vaporize the less refractory metals.

Place a piece of metal in the spoon; when it oscillates fast enough the flame will be filled with its corpuscles and will be colored with the color that the metal is able to generate. The metal may have one rate, as thallium, or many; but whatever rates it may have the prism P will separate them and project a spectrum on the screen S S. And the spectrum will present bright lines due to the metal. It will not be continuous. All parts of the band will be dark except where the thin strips of light—images of the slit—fall. Each mode of matter vaporized gives a different set of lines. Now, when the bright lines are on the screen turn on the white electric light from the lantern and pass it straight through the Bunsen flame. Instantly all bright lines on the screen turn black, and all black parts of the spectrum are filled with light, the Bunsen flame allows all waves to pass through except those rates due to the vaporized metal within. That is the law of Kirchhoff.

Cut 20 is far better than this method of a flame in the open air. At the left is an apparatus for the production of hydrogen gas. Next is the electric lantern as in 19. Then comes an iron furnace with chimney above. A long iron tube passes directly through the furnace, and can be brought to a great heat. The tube has a glass window at each end. The air is expelled from the pipe, which is now filled with hydrogen—to be rid of oxygen. Any metal whose point of vaporization is less than that of iron is put into the vertical tube up through the roof of the furnace as shown. The pieces of metal slide down into the tube and hydrogen. The fire is now lighted in

the furnace and the metal is turned into a vibrating gas. Then the powerful white light from the electric lamp is passed lengthwise through the glass ends of the tube and falls into the slit of the spectroscope on the right for analysis. Absorption



Cut 20. Lockyer's Absorption Furnace and Spectroscope.

bands and lines can be measured with the micrometer and recorded.

There are other more modern ways of studying absorption. And the absorption lines of all modes of matter so far discovered are tabulated.

IX.

EXPLORATION OF THE UNIVERSE.

"For consider, Purna, that great vault of space, the sun shines forth and there is light, the clouds gather and there is darkness, the winds arise."—Kiounen Sutra, Chinese Scriptures.

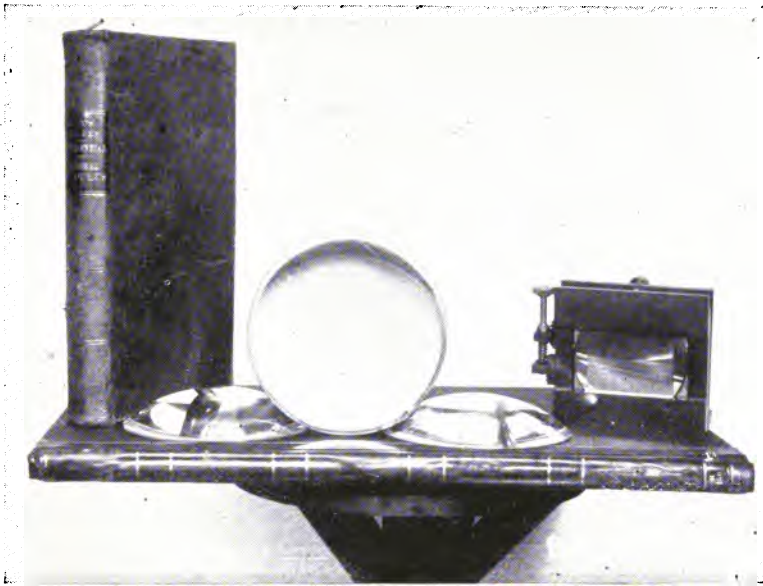
"But if darkness, light and sight be separate and independent, one of the other, then if you remove light and darkness, there is nothing left but void space."—Buddhistic Sutra.

In cut 21 are shown three of the most valuable instruments in the possession of scientific men—three mighty engines for the conquest of nature. They explore the mysteries of the sidereal universe, and reveal its secrets. Without a full knowledge of these three and how to use them, man must have forever remained ignorant of the vast cosmical structure in which he finds himself an inconceivably minute portion.

The dust in the air in the room in which the reader may be is larger in proportion to the space in the room, than the earth is to space revealed by the telescope.

The lenses shown bring energy into the slit of the spectro-scope from our own and countless suns besides, and from nebulae in the limitless sea of space, and projects the telltale waves upon the grating. This analyzes them and makes known the conditions of matter sending the tiny undulations. It becomes known what the structure of nature is composed of. And that other lever to pry up the universe, the differential and integral calculus, culminates the present achievement of the human brain.

Once let its grasp seize the mechanism and motions of suns and solar systems or anything that can be chained to the servitude of mathematics and all is revealed. No motion can escape its searching analysis; it drags forth the most abstruse and hid-



Cut 21. Calculus, Lens and Grating; three mighty engines for exploring the universe.

den mysteries of matter in all its movements. Without these three, men today would be all unconscious of those majestic laws governing the sidereal structure.

CHEMISTRY OF THE SUN.

Having brought the separate parts of the modern spectro-scope together into a complete instrument, it is time now to use it, beginning with that fascinating work, the chemistry of the sun.

The sun is 1,310,000 times larger than the earth, but the

quantity of matter is only 333.426 times that contained in the earth. How the mass of the sun was found cannot be given in these primitive essays. With this volume and mass its density is only .26 or slightly more than one-fourth that of the earth. The sun sends out in stupendous floods in all directions, energy, solely in the form of waves. It sends forth 2,220,000,000 times more waves than are encountered by the earth.

If waves interfere by odd multiples of half wave-lengths they destroy each other, or if they hit matter in these odd phases they destroy themselves, but if they strike matter in even phases they do an incredible amount of work. They sustain every activity on earth and alone keep up life. But men might have existed on earth until the sun is dead and would have been totally ignorant of its composition had not the spectroscope been studied out. Mass, volume and density do not give any indication of what the mass is composed. The energy must be analyzed and waves to be examined by themselves must be separated from all the others and this is done by prism or grating.

COMPARISON.

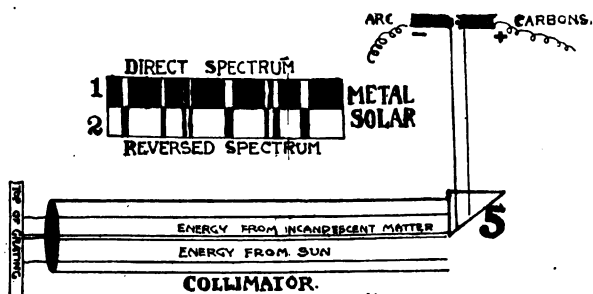
The comparison of energy from the sun with that of terrestrial substances when oscillating under the action of heat, is performed by passing waves from the sun and substance through the slit at the same time side by side. The bright lines from some phase of matter on earth will then fall end to end against dark absorption lines from the sun if there are any.

This is shown in cut 22, where waves from some incandescent metal is passed through the slit, and they will form a spectrum. To the right of the slit at 5 in cut 15, and at 5 in cut 22 is a small right-angled prism, so that light entering a side is reflected at right angles from the hypotenuse as shown in cut 22.

REVERSAL IN THE SUN.

Two arc light carbons are shown with a piece of metal in the crater of the positive. If the metal vibrates at 8 rates, then as soon as the current is turned on, figure 1, cut 22, will be seen on the grating in the upper half of the slit. If now sunlight is projected through the lower half, the grating will show figure 2. There are 8 reversals, and the ends of both sets of lines coincide. It is at once inferred that the same metal is incandescent in both the sun and arc.

The terminals of an induction coil may be substituted for the arc, in which case the heat of the disruptive discharge vapor-



Cut 22. Light from Sun and Vaporized Metals compared.

izes the metal, or low metals may be turned to gas in a Bunsen or alcohol flame. In all these cases, however, the differing sets of bright lines (one set for each metal) will come opposite a set of black lines, if the metal in question is reversed in the sun.

These tests have been made by skilled spectroscopists in all parts of the world, and the results have been subjected to the mathematical theory of probabilities, when it is found that the chances of the metal existing in the sun are as three trillion to one.

From the preceding notes it is known that black lines are caused by absorption; for take the metal out of the crater and

place it in a Bunsen flame, between the arc and slit, as shown by the dotted lines in cut 19, then the white light of the arc will pass through the dim flame, all, except the eight rates, set up in the flame. Figure 1 will be filled with every color except the eight lines, which will now turn black. Thus absorption can be produced in the laboratory corresponding exactly with that taking place around the sun. It is clear, therefore, since selective absorption is produced by oscillating gases only, that there must be vibrating gases between the sun and earth as well as between the arc and slit.

These gases constitute that wonderful thing, the atmosphere of the sun. The air there is made up of gaseous metals. If there are other modes of matter in the sun, they are in a state of dissociation, so they cannot vibrate in rates that will form a spectrum—at least in the visible portion—or are obscured by the profusion of metallic vapors on the sun.

Dissociation is Lockyer's theory, and seems to point to the conclusion that there exists but one kind of matter. The sun then contains the same kinds of metals at least that make up the metallic store on earth. And incredible quantities of hydrogen, and helium also.

Professor Charles A. Young, *General Astronomy*, p. 215, Revised Edition, says that the following elements are known to exist in the sun.

Iron,	Calcium,	Magnesium,	Erbium,
Nickel,	Ccandium,	Sodium,	Zinc,
Titanium,	Helium, ,	Silicon,	Copper,
Manganese,	Neodymium,	Hydrogen,	Silver,
Chromium,	Lanthanum,	Strontium,	Germanium,
Cobalt,	Yttrium,	Barium,	Glucinum,
Carbon,	Niobium,	Aluminum,	Tin,
Vanadium,	Molybdenum,	Cadmium,	Lead,
Zirconium,	Palladium,	Rhodium,	Potassium.

There is yet a question as to the existence of oxygen in the sun, while chlorine, nitrogen, bromine, iodine, etc., appear to be missing—or if present, hidden in a multitude of other incandescent vapors.

But the vast work has only started, for there are large numbers of absorption lines not yet identified with matter on earth.

The solar atmosphere is complex; but not disconcerted, however, with the great task, men are now attacking the problem with renewed energy.

X.

SOLAR SPECTROSCOPE.

"As one sun illumines the whole world, so does the one spirit illumine the whole of matter. O! Bharata."—Hindu Bhagavad-Gita, Ch. XIII.

Not only does the spectroscope reveal the constituent types of matter in the sun, but their conditions also. The sun is a mighty globe whose surface and regions above are in a state of excessive turbulence, upheaval and unrest. The most appalling explosions of pent-up gases, heated to temperatures far higher than known on earth, continually occur. Terrific cyclones and hurricanes rend the sea of incandescent vapors, and hot metallic winds blow with the most incredible fury. In the ninth paper it was shown how the spectroscope tells the composition of solar gases, by means of readings of absorption lines, the entire story being told by short thick and thin black lines. These and the adjacent colors are all that can be seen in a spectroscope as ordinarily arranged in the laboratory. But the sun itself cannot be seen in this manner; for the mirror of the heliostat does not magnify, or if a lens is interposed between the mirror and slit it merely serves to make a small image of the sun on slit plate.

But now a giant lens must be placed between the sun and slit, and the heliostat removed. In short, the spectroscope must be transformed into a telespectroscope; that is, be attached to the eye end of the great telescope in the dome of the observatory, the physical laboratory being closed.

The new apparatus—the telespectroscope, is shown in cut 23, where the spectroscope so far treated in these notes is seen fastened to the end of the sixteen-inch telescope, the extreme lower



Cut 23. Telespectrograph in the Lowe Observatory.

end of which appears. The great lenses are in the other end of the steel tube and are twenty-two feet higher in the top of the dome and pointed straight toward the sun.

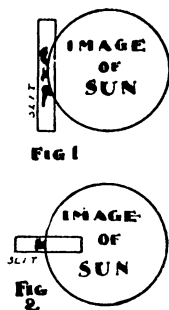


Cut 24. Fig. 14 Lens and Tube for Projecting Solar Image on Slit;
Fig. 15. Slit for Solar Spectroscopy and Vernier.

The slit for sun work is shown in cut 24, figure 15, where the slit is opened hundreds of times wider than when in use, for if narrow it would be invisible in cut. The movable arm and vernier upon which the figure 15 appears, slides around the ruled circumference and reads the position angle of any object that may be seen on the apparent edge of the sun. These angles are read from the North Pole of the sun and serve for future reference in making daily record of solar phenomena. It also rotates a tube behind the open slit. This tube contains a prism seen back down on the table to the left of the solar slit and circles, which makes the image of the sun appear to revolve around the axis of collimation of the telescope. Thus the entire periphery of the sun can be brought rapidly into view.

The vertical brass bar containing the slit also has a vernier on the opposite side of the circular plate, by means of which the position of the slit on the edge of the sun can be read. The prism inverts everything. Looking through the slit and prism

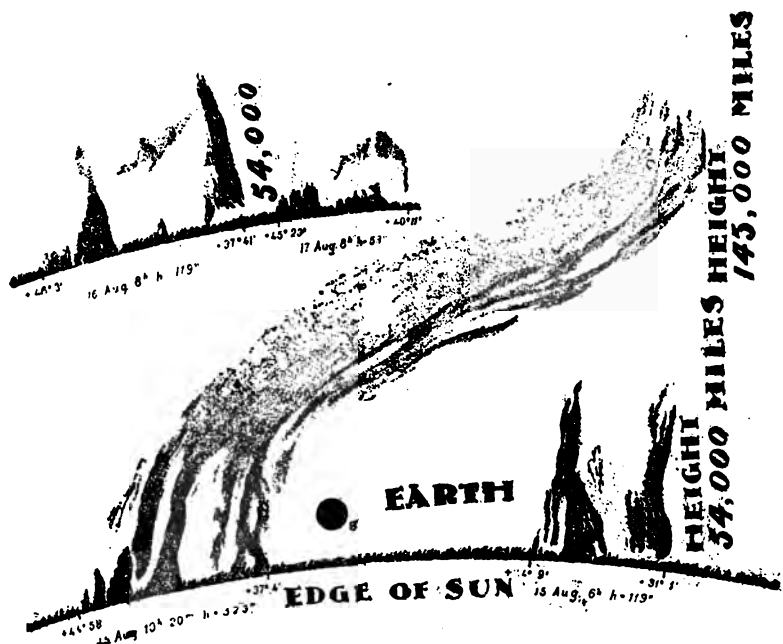
at a distant house, the chimney appears all right, but if the cross-bar and tube with its prism be turned, the chimney will point to the center of the earth and to the sky, alternately. When the great object-glasses of the telescope are gazing at the sun they form an exceedingly brilliant image of the sun at their focal plane, at 1, cut 23. This image is two inches in diameter, and the edge is allowed to fall on the narrow slit, now closed down to a width of 1-1000th of an inch.



Cut 25. Images of Sun and Slits.

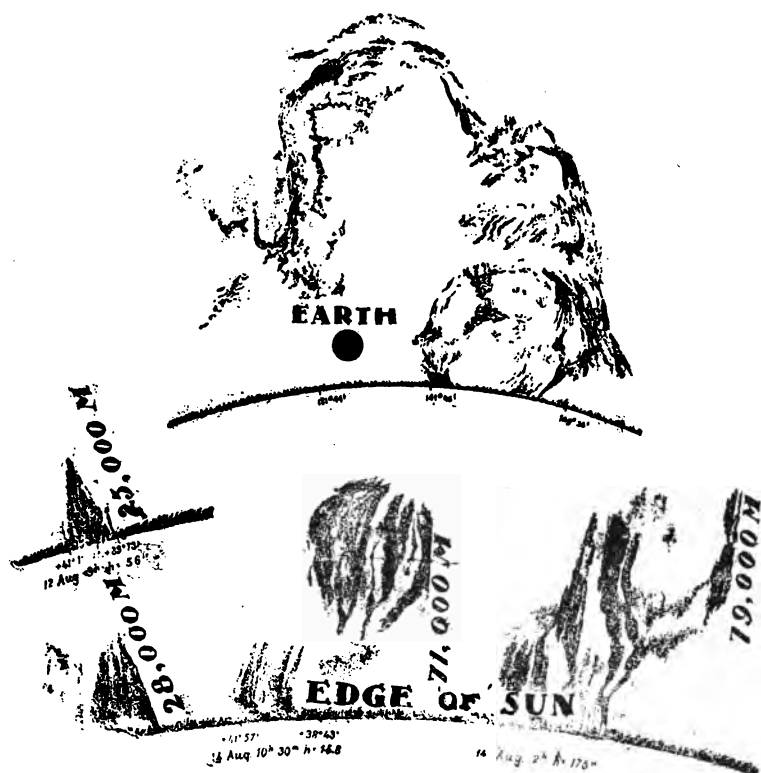
This is made clear in cut 25, where a front view of the top of the slit end of the collimator, figure 1, cut 23, is shown. In figure 1, cut 25, the slit is tangential to the solar image, and in figure 2, radial, the light enters the slit and falls on the grating in the circular box at 2, cut 23. Here the light is diffracted into a long brilliant spectrum. It is the spectrum of the sun. It is reflected by the grating to the spectro-camera at 3, where it is graphed and filed away for future study and comparison with later graphs. Or by taking off the plateholder, an eye-piece can be attached for viewing solar explosions directly, for an eye (at the eyepiece) is liable at any time to see colossal explosions hurling white hot matter to vast heights with terrific velocity.

They are of all shapes and sizes, a few types being shown in cuts 26, 27 and 28. The lowest in any of the figures is 25,000 miles high and the highest shown is 145,000 miles. The three black dots



Cut 26. Edge of Sun Showing Explosions. The Dot is the Earth's Exact Size.

in 26, 27 and 28, represent the size of the earth in comparison. In cut 26 is seen a portion of the sun with six spots, and the small dot is also the size of our earth in proportion to the sun, explosions and spots. Sun spots have been measured whose area was 32 times that of a section of the earth, so 32 worlds like the earth could tumble in side by side with room to spare. The tele-spectroscope therefore renders the prominences visible and



Cut 27. Limb of Sun Showing Explosive Prominences, and Relative Size of the Earth.

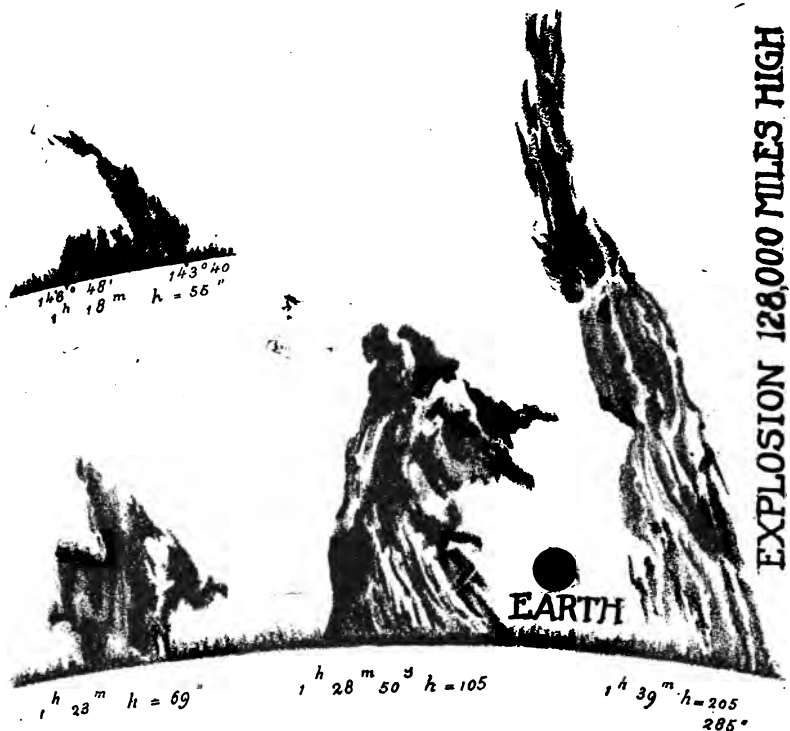
tells what they are made of when the telescope alone could not do either. The philosophy of enabling the eye to see the protuberances is that the grating displaces the mixed white light of the atmosphere of the earth. All know that the sky round about the sun is white, due to diffusion of light by dust and aqueous vapor in the air. But the spectroscope draws this white into a long band of colors, weakens the glow and intensity of radia-

tion. This is because the light is white. But an explosion on the sun may be red, each set of waves being of the same length. They therefore cannot be dispersed farther; images of the slit of any object whose light enters it will be separated by wide distances, but their brilliancy will not be lessened. An important result follows: They can be seen bright on a dim background. This is a great achievement in solar work, for before this discovery astronomers had to wait until a total eclipse of the sun



Cut 27A. Explosions on Sun; Also a Few Sun Spots in Comparison With the Earth.

occurred. In that case, the moon cut off the sun, but left the prominences in view for a very short time. Thanks to Lockyer and Janssen, these wonderful objects on the sun can be seen in full daylight. In cut 25, figure 1, the slit being on a tangent to the sun's image, happens to include three explosions. They can be either analyzed or photographed. Figure 2 shows slit radial, it is not wide enough to take in more than one upheaval. By rotating the arm 15 in cut 24 the entire circumference of the sun may be brought before the slit in a short time, and every outburst photographed. And men are making perpetual graphs of the sun, a continuous record for coming generations.



Cut 28. Explosions on the Sun and Comparative Size of Our Earth.

The sun cannot make an upheaval without being instantly photographed somewhere on the earth, the imperturbable eye of man is ever on the sun, for when it is setting at one place it is rising, or is at meridian altitude, at some other. The sun is now writing its own history, and it is a most interesting diary.

It is thought that a graph taken now and one ten thousand years hence may show changes in the constitution of the solar mass, and that men by that time will have accurate knowledge concerning that stupendous star, the sun.

XI.

SPECTROSCOPY OF THE SUN.

"First the world was void,
The first light was Aum;
Thence the alphabet,
The seeds of the universe!"

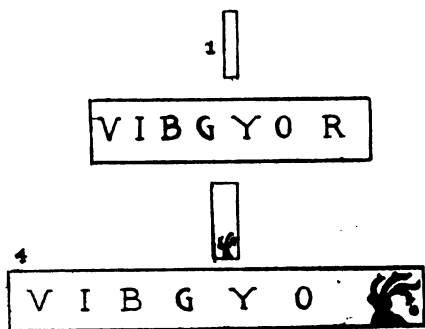
—Primeval Aryan Literature, Hodgson's Trans. Royal Asiatic Society, II, 332.

Since the continued existence of the human species on earth depends entirely on the radiant energy sent out by the sun, this splendid star must naturally be the subject of admiration and solicitude, now as well as in prehistoric times. The vast field of research and exploration has scarcely more than been entered. The combined energies of man must be centered on the herculean work of taking energy out of space and chain it to his servitude. Men pay for power now; it should be free.

All problems so far presented to men for solution fall into insignificance in presence of the mighty problem of the ages—how change the lengths of waves from the sun and make them fit for human use? The question how the spectroscope makes the solar explosions visible is important and needs further study.

In cut 29, figure 1, is shown a slit filled with white light. In figure 2 is the same slit magnified. It is clear that if no additional quantity of light has entered, the band will be much weakened

in brilliancy after being spread over so much greater area. And the prism or grating would spread it over the entire belt if the light were white, but not widen it at all if the slit contained red or blue or any other homogeneous waves. This is because white light contains waves of every degree of refrangibility—capability of being bent aside—and homogeneous light only one degree. This is the secret that renders prominences on the sun visible without an eclipse.



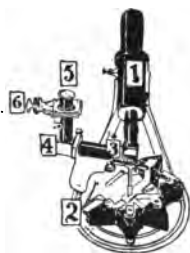
Cut 29. Fig. 1, Slit. Fig. 2, Slit Magnified. Fig. 3, Slit with One Explosion in the Red End of the Solar Spectrum.

Cut 29, figure 3, represents a wide slit, with the dim outlines of an eruptive prominence on the edge of the sun, invisible to the eye or to a low-power spectroscop, for the white light is as bright as whatever may be the color of the cast-up matter. In figure 4, the wide slit is magnified still wider by a high-power spectroscop, its white light widely dispersed and greatly weakened, while if the explosion is of any homogeneous color—say red—its light is not dispersed and is not fainter. It is visible against the dim spectrum, due to the dispersed white light as a background, and appears in the place of red.

WIDE DISPERSION.

The process of being rid of the white light diffused in the earth's atmosphere is shown in cut 30.

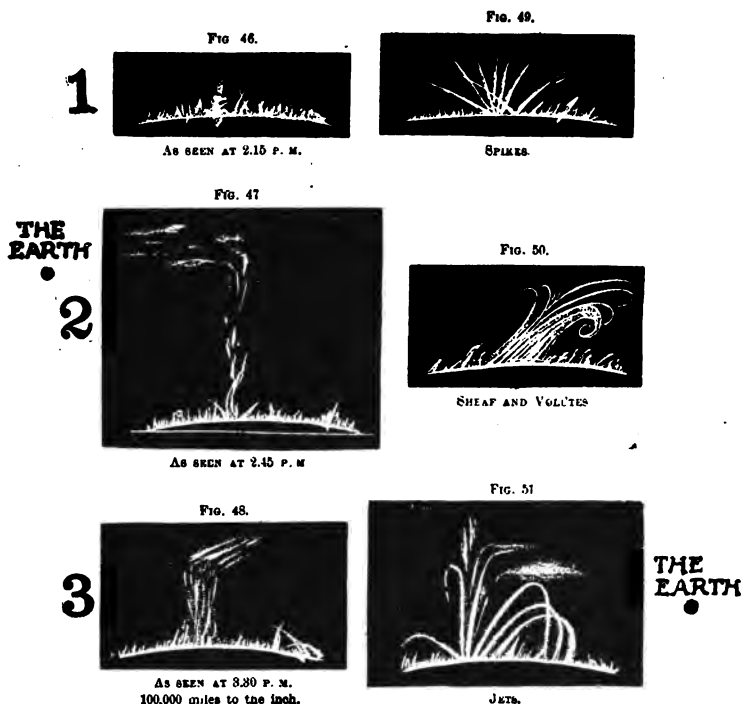
The prismatic telescope in cut 30, takes the place of the Lowe grating telespectroscope on the end of the great telescope, as shown in cut 23, Chapter X. Figure 1, cut 30, is over the slit in the collimator tube, the screw for opening and closing



Cut 30. Prismatic Telespectroscope.

the slit being to the left of (1). The light from the edge of the sun comes through it and falls on the lower half of the first prism in the train. This disperses the light somewhat and projects it against the lower half of the next, and so on to the terminal prism, marked (2), upon whose hypotenuse falls the spectrum. This reflects it without change through the top half of the first prism, and on through the tops of all until it emerges from the last and enters the open tube (3) as a beautiful spectrum. It encounters a rectangular prism in the brass box (4), which reflects it up to the eye-piece (5), through the micrometer (6).

An eye placed at (5) may at any time during the day see an explosion as shown in cut 31, figure 1, for instance, where quite a number of ordinary prominences are shown, giving no indication of the mighty upheaval soon to occur.



Cut. 31. Solar Explosions; Figs. 1, 2, and 3 Show the Great Rapidity of These Turbulent Masses.

Figure 1 is as seen by Professor Charles A. Young of Princeton, N. J., College, at 2:15 p. m., July 25, 1872. Figure 2 is at 2:45 p. m., 30 minutes later, and 3 is the same at 3:30, after an interval of 45 minutes. The scale is 100,000 miles to the inch, and the earth is shown in exact size to the left, just above the figure 2. The height of the explosion at 2 is 125,000 miles, the vertical ascent being 100,000 miles in 30 minutes. When it reached this altitude it seems to have been caught by

a mighty wind of hot metallic vapor and bent over to the left at almost right angles. These outbursts are classed as "the quiescent, cloud-formed, or hydrogenous, and the eruptive, or metallic." Young, Seechi, etc.

The quiescent are composed mostly of the light gas hydrogen, but the eruptive look like jets, spikes and projecting horns. They change form rapidly, and are made of such metals as magnesium, barium, sodium, iron and titanium and others at terrific heat. Several spikes and jets are shown in cut 31, and also the dimensions of the earth to the right of the jets. The highest prominence, accurately measured, reached a height of 309,000 miles. A. P. J., October, 1901, page 213. The explosive prominences at times are so intensely brilliant that they can be seen on the disc of the sun far away from the edge, being much brighter than the solar surface, which in turn is many times brighter than the light of the most powerful electric arc yet produced. Their velocities of ascent range from 50, 75, 100, 150, and a few have been measured with the incredible speed of 250 miles per second. With what terrific force they were shot forth from the sun. Perhaps at the instant of outburst the metals were in gaseous form so dense as to be almost liquid. Cyclones twist up white hot matter to great heights, and in some cases the tops of these expand into thin clouds and remain up for several days floating upon the upper layers of denser gases beneath.

Professor W. W. Campbell of the Lick Observatory, in his lecture to the Southern California Academy of Sciences in Los Angeles, on March 11th, 1902, presented a series of photographs showing that some of these outbursts are intimately related to sun spots. The mystery of the sun is the vast quantity of hydrogen extending entirely around it in sheets or layers, and also being incessantly hurled forth from below the apparent surface with a force thousands of times greater than that of hissing steam from a high-pressure boiler.

In cut 30, figure 6, is shown that powerful instrument, the spectro-micrometer. It measures every object in the field of view with extreme accuracy. The screw carrying the wires is shown to the left, close to the 6. The value of one turn of this screw in seconds of arc must be found by astronomical methods. When this is determined the wires can be removed up so as to just include an explosion or spot between; then the screw may be turned until both wires coincide and appear as one. The number of turns multiplied by the value of one turn in miles or kilometers, gives the height or diameter. The angular diameter of the sun is 1,924 seconds of arc; and its distance is 93,000,000 miles. From an elementary rule in trigonometry it is known that one second is 450 miles on the solar disc. If a prominence extends to the height of five minutes, or 300 seconds, its altitude is 135,000 miles.

Measures are recorded of all these that are worthy of record. But of all records yet devised, those made by the photograph are the most accurate. This leads to that high branch of research—solar photography.



XII.

RADIANT ENERGY AND ITS FIXATION.

O Thou of whom all is the manifestation,
Thy nature is the spring of thy being:
Whatever is, is thou;
We are all billows in the ocean of thy being;
We are a small compass
Of thy manifested nature

—From Dabistan, Vedantic Phil., Hindu.

This paper might more properly be called radiant energy and its fixation. For now radiant and oscillating energy is to meet cessation, the waves are to do work on particles of silver, leave their records and come to rest. The sun must do writing and imprint graphs of its daily work, ceaseless turbulence and upheaval.

The water at the foot of Niagara is not more turbulent and not tossed and torn into more fantastic shapes than is the seething surface of the sun. But how shall these fleeting forms be photographed, and by what possible means can an explosion hurling up white hot jets 40,000 miles wide and 200,000 high, with the terrific speed of 200 miles per second be instantly portrayed on a sensitive plate so as to appear at rest, like the spokes of the driving wheel of a locomotive moving a mile a minute? And the heat—will not the great heat of the sun destroy plates and prevent light from making record? These were the problems that were encountered by astronomers from the year 1850. Not only must the prominences be made to record their forms, but spots, faculæ, granulations, filaments, solar clouds and corona had to be made to appear on the films; but of far more importance, the

solar spectrum also was required to make imprint, or little could be learned of the constitution and structure of that majestic object—the sun. And then came workers who knew no rest, whose labors were more arduous than those of Hugo's "Toilers of the Sea."

In a preceding paper a cut was inserted showing three colossal engines at work for the enlightenment of man, the calculus, lens and grating. To these must now be added a fourth, the gelatine bromide plate. It brought work, toil unknown in intensity outside an astronomical observatory. The sensitive plate now takes rank with the discoveries of the ages—like the Copernican system, the laws of Kepler, the law of gravity, the invention of the telescope and spectroscope, the multiplex telegraph, induced electricity, the dynamo, the wireless telegraph and telephone, Hertzian and Roentgen waves, the obscure radiations of the Curies, liquid hydrogen and slow but sure approach to the end, the absolute zero.

Those who reared the pyramid of Sulphis, dug the Suez Canal, tunneled mountains, made ocean steamers, laid the Atlantic cable, bridged Niagara, laid the railways of the earth and set up the dynamo, did no more remarkable work than the toilers who, from 1834 to 1902, wrought, day and night, to bring astronomical photography to its present high estate—to the fullness of majestic science. The plate is displacing men from the eye-end of the telescope, the human body, nerves, brain and eye, with all their forms of personal idiosyncrasy, imperfections, limitations and errors, must go; the plate makes no mistake. Not less remarkable were researches on the application of photography to astronomy than were those so long and persistently made to find the cause of the Fraunhofer lines.

The first attempt to photograph the sun, or rather its spectrum, was made by Professor J. W. Draper, in 1834. He had merely a sheet of paper roughly coated with silver bromide. He

failed, but the effort was a turning point in human advance. He took a small daguerreotype of the moon in 1840. M. Daguerre having discovered his process on August 13, 1839. Draper, in 1842, and Becquerel, both made types of the moon, and in 1843, made a graph of a rough diffraction spectrum.

Foucault and Fizeau, on April 2, 1845, actually produced a daguerreotype of the sun. Then came Bond, in the now historic Harvard College Observatory, and took graphs of the moon in 1850, and copies were exhibited in London on May 9th of that year. On July 17, 1850, Bond and Whipple took the first photograph of a star, the star Alpha Lyræ.

In 1851 Busch took the first graph of a solar eclipse. All these were daguerreotypes. Then came the collodion process, and De la Rue, in 1852, took graphs of the moon by means of wet plates. On June 9, 1854, Hartnup presented ten collodion graphs of the moon to the Royal Art Society in London.

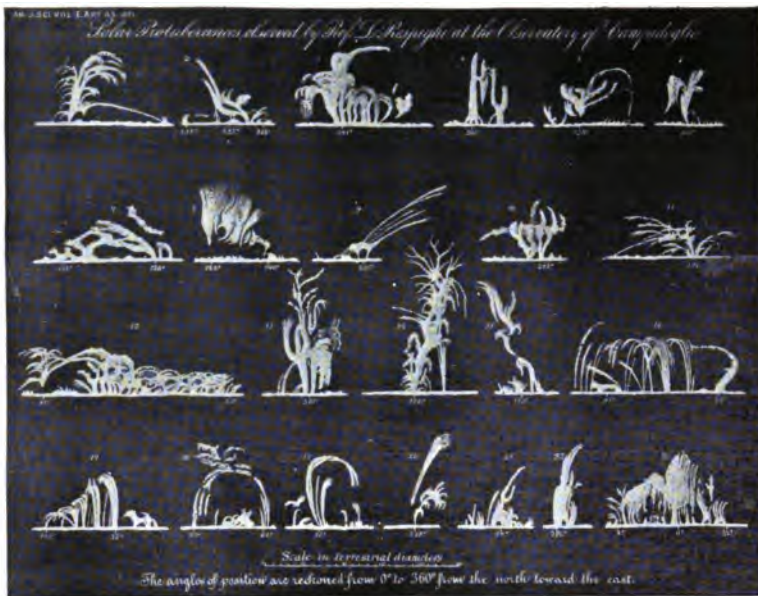
April 24, 1854, was a prophetic day, for Sir John Herschel recommended that daily photographs of sun spots be made. From 1857 to 1863 Professor Henry Draper made many collodion graphs, 1,500, of the moon, with ever increasing definition. In 1857, Bond, with more sensitive collodion plates, photographed stars, even to the sixth magnitude. He began a historic movement, for he measured the distances between the minute dots, the stellar images, giving rise to accurate determinations of star motions, if any are shown on later graphs. Rapid advance was made from 1857 to 1860 by many physicists, most notable of all being De la Rue, Bond and Pritchard. Rutherford began his great work in 1858, and made research on lenses and mirrors. July 18, 1860, is memorable, for De la Rue and Seechi both secured graphs of the total solar eclipse of that date in Spain, and proved that the prominences were actually on the sun and not an optical illusion on the edge of the moon, for the advancing edge of the moon covered and uncovered the scarlet jets and

heaps. On February 27th and March 3d, Huggins obtained a graph of the spectrum of the star Sirius. It was not until 1865 that Rutherford discarded lenses corrected for visual waves and made objectives corrected for those waves only making the best action on salts of silver. This placed modern astronomical photography on a strictly scientific basis. His graphs were marvels of definition and perfection. On November 28, 1870, that eminent American astronomer, Professor Charles A. Young, photographed the prominences on the sun without an eclipse. In 1874 photography was used in recording the positions of the planet Venus in its transit across the solar disc. These positions are used to obtain the distance of the earth from the sun. All the graphs so far taken were on collodion plates. But now comes a most important improvement—record breaking so it proved.

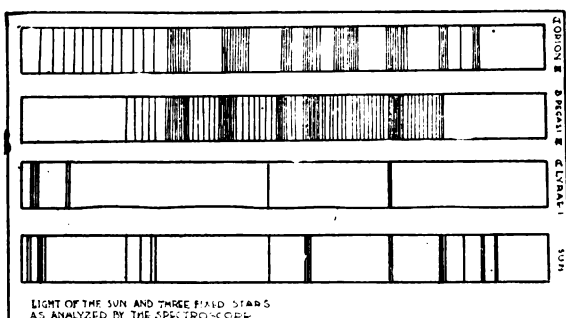
DRY PLATES.

That auspicious year, 1876, came, and with it gelatine dry plates sensitive enough for astronomical graphs. Immense impetus was at once given to graphic research, for these plates could be exposed for hours, on faint work, all night, in fact, if at work on stars and nebulae. The gelatine film holds the particles of silver bromide in place so they will store the radiant energy of the universe. Now storage of energy is the highest achievement of human hands. Huggins soon stored energy falling on the earth from the star Vega, and saw on his plate seven strong absorption lines. On July 20, 1877, Draper discovered oxygen in the sun, and from this time astrophysics made the most rapid progress since the primeval Aryans watched the stars from the uplands of Central Asia.

Exceedingly rapid exposure is made for sun work, and extremely slow for faint star graphs. Photographs may be taken hourly of the prominences, as well as spots, faculae, or the entire disc.



Cut 32. Solar Prominences; Mainly Hydrogen; Helium and Gaseous Metals Also.



Cut 33. Spectra of Four Suns; Alpha Orionis, Beta Pegasi, Alpha Lyrae and Our Own Sun at the Bottom of Cut.

Cut 32 reveals a number of forms of solar explosions. Their height varies from 20,000 to 160,000 miles, the lowest shown being about three times the diameter of the earth in height. These gigantic outbursts are of a bright red, against a dull red back-

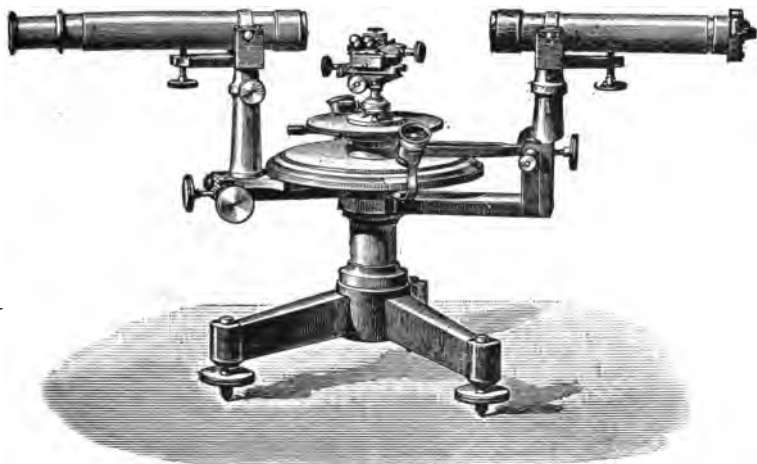


Cut 34. Total Eclipse of Sun; Showing Corona; the Black Center is the Moon.

ground in the spectroscope. Their composition is largely hydrogen.

Cut 33 shows spectra of four suns, Alpha Orionis, Beta Pegasi, Alpha Lyrae, and our own sun being at the bottom.

Cut 34 is that of a total eclipse, showing the black body of the moon in front of the sun, cutting off its light, allowing the explosive prominences to appear around the edges; with the great streamers of the corona far beyond. This photo was taken without a spectroscope, as no dispersion was required.



Cut 35. Ordinary Laboratory Spectroscope.

Cut 35 is that of an ordinary Browning spectroscope used in a laboratory for making analysis, and is not used in astronomical researches.

XIII.

SOLAR SPECTROGRAPHY.

"His radiance is undecaying."—Rig Veda.

"The royal sun feedeth all."—Sophocles Oedipus Tyrannus 660.

This has now become an important branch of work in a modern astrophysical observatory.

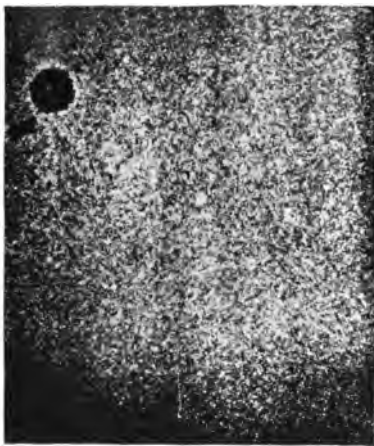
The year 1877 was also auspicious, for Janssen rose up and photographed the sun with clearness of detail not reached before. His graphs were one foot in diameter, and displayed intricate tracery of the sun with sharp definition. Countless tops of prominences appeared on his plates, all over the solar disc, where before the sides only of the exploded masses on the limb of the sun were seen.

His solargraphs show granulations, shaped like grains of rice, and a network of distorted forms of white hot matter below or round about. The solar surface is mottled and looks like the elevations and depressions of very coarse and rough blotting paper, as seen through a low power lens.

Janssen says: "The forms generally have rounded contours, but some are rectilinear and others polygonal, and in the intervals of this network the rice-grains are distributed, the granules being half obliterated, drawn out and confused." Popular Astronomy, Vol. II, 312, H. C. Russell.

The success of this intensely difficult work was reached by

reducing the time of exposure of the sensitive plate to the 1-3000th part of a second. The evanescent, rapidly moving and fleeting tops of the heated jets were caught on his plates and rendered motionless, among scenes of the most appalling unrest and explosive, cyclonic and disruptive activity.



Cut 36. Janssen's Photograph of Solar Disc; Showing Granulations.
or Tops of Prominences and One Spot.

Cut 36 is Janssen's photograph of the solar disc showing the roughness and granules supposed to be the crests or tops of the jets and prominences. Two spots are also in range of the camera.

In 1878 Dr. Henry Draper photographed the spectrum of the sun's corona, seen at the total eclipse, and showed that the corona shines by reflected light. There must be matter near the sun to reflect, and this is conceived to be in vast banks of exceedingly fine cosmical dust, so fine as almost to assume the properties of a gas, for comets have been seen to tear through it

with the terrific speed of 200 miles per second without retardation or disruption.

The first mention of this wonderful halo round about the sun is by Plutarch, as seen at the total solar eclipse March 20, A. D. 71. It was not mentioned again in the literature of astronomy until near the close of the sixteenth century; since when it has been watched and studied with ever increasing interest and accuracy.

It is well to make close study of the sun, for it is merely a small star, and being so near the earth, every fact gained by comparatively easy means, will be of great use when that other branch, stellar spectrography is reached. If a journey from the earth to the sun be made, the first matter encountered as the sun is approached will be the solar corona, an object extending in gigantic streamers into space from 300,000 to 2,000,000 or more miles. It is a luminous body and is truly solar. The diffused light of the earth's atmosphere makes a white halo around the sun's disc totally obscuring this crown worn by the sun. But when the moon cuts off the sun's fierce light at times of total eclipses, the delicate filaments of the corona are seen in magnificent display. It is made up of long bright streamers and at times darker spaces are observed between them.

The intensity of coronal light is about three times that of the full moon, but varies at different eclipses, and while intense near the sun, it rapidly wanes with increasing distance.

The corona seems to be made up of three portions. There are filamentary streamers and bands emanating from the polar regions of the sun, and these are almost straight. The bands near the sun's equator and close to the surface are curved, and at some eclipses long streamers rise high above these in the equatorial regions. Slow changes in the form of the corona are taking place, but no rapid displacements, like those seen in the jets and prominences below, have been detected.

In the eclipse of 1893 the corona was photographed in Chile, South America, and two and one-half hours later it was also graphed in Africa, and both pictures were identical. Yet, no two eclipses present the same forms. The changes appear to follow the eleven-year spot period. At the times of sun spot maxima the coronal streamers are short, brilliant and of complex structure, but in spot minima, the corona is irregular, with short tufts around about the poles of the sun; and also extremely long streamers reaching distances of two or three million miles, along the plane of the earth's orbit. The streamers look somewhat like an aurora on the earth.

Total eclipses during a hundred years afford only an hour or two in which to study the marvelous object. Spectroscopists are always busy in the midst of an eclipse; in fact a long row of spectroscopes are set hundreds of miles apart on the earth's surface, good care being taken to have all the observers in the center of the line of totality. The coronal light projects a faint continuous spectrum, and from Kirchhoff's first law it is known that the light comes from incandescent solids or liquids. Projected on this background is seen a bright line spectrum. The second law of spectroscopy teaches that this spectrum is cast by light from glowing gases.

The gas most plentiful in the corona is hydrogen. But a most mysterious double line in the green region numbered 1474 is also observed. One of these lines is due to iron—that is, it coincides end to end with an absorption—black—line in the spectrum of the sun's surface far below.

But the other line does not coincide with the line of any mode of matter yet found on the earth. And now chemists and spectroscopists are ransacking everything on earth to find it. The eagerly sought substance is named coronium—the name will be all ready to put into telegrams that will be flashed to every observatory in the world by the fortunate spectroscopist finding it.

The gas helium was seen casting its line in the solar spectrum for years; and the earth was turned bottom side up to find it here, and it was actually discovered by Ramsay in 1895 in the mineral called cleveite.

An exceedingly refined spectroscopic observation was made by Deslandres which proved that the corona revolves with the sun. If a source of light either approaches or recedes in the line of sight, the spectroscope at once detects the motion. He photographed the spectrum of the portions of the corona on opposite



Cut 37. Total Solar Eclipse, Showing Lower Portion of Corona.

sides of the sun and saw that the tufts and streamers on the east side of the sun were moving toward the earth, while those on the west side were receding. But the sun also revolves from west to east.

Cut 37 is a total solar eclipse of sun showing matter hurled up on the edge of disc.



Cut 38. Trouvelot's Total Solar Eclipse ; July 29, 1878.

Cut 38 is the magnificent drawing made by Trouvelot of the great corona of the total eclipse of July 29, 1878, made at Creston, Wyoming. The polar streamers and equatorial extensions are shown in detail, also the glorious corona of the sun.

XIV.

SPECTRUM ANALYSIS OF THE SUN.

"In the beginning there arose the source of golden light."—Rig Veda, Ch. 10-121, B. C. 1500, Aryan Scriptures.

"From darkness lead me to light."—From "Brihad Upanishad," Hindu Philosophical Poem.

Elaborate study of the sun's surrounding can only be made at times of complete eclipse. The light and heat from the disc are so intense that close examination of the photosphere and corona cannot be made until the welcome moon comes along and cuts out the sun, leaving the external banks and clouds of incandescent gases in plain view. It must be an occasion of wonder and surprise to many to see the civilized nations of the world, as well as universities and observatories send costly eclipse expeditions to remote parts of the earth to watch the extinction of the sun, which they know can last but a few minutes.

In cut 39 is shown the path of the eclipse of January 21, 1898. The black line from Africa through India to Eastern Siberia is the path of total obscuration of the sun. Any astronomer to see the splendid and impressive spectacle must be within this track. The widest possible shadow is 167 miles, but usually the width is much less. The mechanism of the solar system is known with such accuracy that the exact places on the earth where the eclipse will be total is computed years beforehand. So,

spectrographs, telescopes, polariscopes, etc., so a man is stationed at a chonometer to announce the fleeting seconds. When he calls the time, each human machine moves in a carefully prepared programme. Since the invention of that wonder of the ages, the dry plate, and the rise of that vast science, spectro-photography, expeditions are sent to the ends of the earth to secure permanent records—that is, photographs of all phenomena seen at



Cut 40. Professor Campbell's Eclipse Outfit, Jeur, India.

the eclipse, as shown in the telespectroscope. This is an instrument of great power attached to the telescope, whose objective collects the light emanating from gases near the sun and projects them into the spectrograph. This analyzes the waves, sorts them out according to their rates and lengths, and spreads them upon the plate, to make graphs to be stored for coming generations. Complete records are thus made of every eclipse, unless obscured by clouds.

The graphs of the Indian eclipse were the best ever secured to that time. Everybody went armed with the best instruments known to science. It was agreed to obtain the best negatives possible of the corona and prominences, but above all to record the "flash spectra" of both contacts. Many parties went to India.

The Lick Observatory sent an expedition under the direction of Professor W. W. Campbell, and cut 40 is his station at Jeur. The great inclined tube is a telescope of forty feet focal length. Its lower or photographic end is lowered into a pit eight feet deep, where the object glass above projects an image of the sun five inches in diameter on the sensitive plate, in its focal plane. Nothing can exceed the skill required to mount all these instruments, before the day of the eclipse, with such accuracy that the sun will come exactly in front of the objective at the supreme moment. After the momentous event Professor Campbell sent this telegram to the Lick Observatory:

"The most satisfactory photographs of the corona were obtained with the three different telescopes. One set with a telescope forty feet long, and two other sets with five-foot and three-foot telescopes. The great equatorial extensions of the corona, which formed such a conspicuous feature of the eclipse of January, 1889, has again been photographed. Also satisfactorily photographed the changes in the solar spectrum at the sun's edge with the aid of one of the spectroscopes."

Professor Burckhalter, of the Chabot Observatory, was also present with the Pearson telescope.

THE FLASH SPECTRUM.

The most consummate skill is required to secure a spectrum of the reversing layer. The highest type of the genius of man is on display here. He must have every instrument ready and

every adjustment made with accuracy before the critical time. The flash spectrum must be secured within two seconds, or the journey of 10,000 miles will prove a failure. Photographing the flash spectrum is one of the chief results of modern research on the sun, and should be understood. The true surface of the sun is doubtless invisible from the earth. Its condition is unknown, but, since the entire sun is only 41 per cent more dense than water, the density must be greater at the center and least at the surface. The sun is in all probability made of liquid gas due to its own pressure. This may sound anomalous, but compress hydrogen under a piston to say one-fiftieth its normal volume, remove the pressure—the gas will expand and the piston rise. The sun is not a permanent liquid, like water, and if solar gravity could be removed the sun would expand to planetary distances no doubt. It is inferred that the sun's surface is a liquid gas of low density, in a state of terrific heat and intense brilliancy. Above this, entirely around the sun, is a deep layer, or envelope, the photosphere, and this is what is seen in the telescope.

THE CARBON PHOTOSPHERE.

Recent researches have led to astounding conclusions as to its composition. Perhaps the concept of Sir Robert Ball is the absolute truth on this important subject; for man lives only by radiance from the photosphere. It is now known that carbon exists in the sun. This, in solid form on earth, appears in diamonds, charcoal, coal and coke, and is the most difficult of all known substances to melt or make liquid. Its specific gravity in gas or in finely divided particles, as in smoke, is low. It easily rises through the earth's atmosphere against gravity. The appalling heat of the sun is able to turn even refractory carbon to liquid, and then to gas. Its gas will rise through the dense

metallic vapors surrounding the sun into cooler regions, condense into liquid drops, or possibly into solid diamonds, and fall and collide near the solar surface. The collisions form the photosphere, therefore the photosphere of the sun is literally a colossal storm of rain and hail of liquid and semi-solid diamonds.

Diamonds are not stones—they are chemically pure carbon, and will unite with oxygen without residue. And this is the latest conception of that marvelous thing—the photosphere of the sun. Metals allowed to resist electricity are instantly vaporized, and the reason why carbon is used in arc lights and incandescent bulbs is because it does not liquify. The brain cannot conceive the brilliancy of the white-hot carbon rain in the sun's photosphere, nor imagine the degree of heat. Other refractory substances, as silicon and perhaps some metals, rise in gas, condense and fall; but none fall back so far as carbon where they are again turned to vapor, so the layer nearest the actual solar surface is pure carbon—a thick shell of liquid diamond, with here and there a white-hot semi-solid gem.

But above this, entirely around the sun are piled up colossal heaps and tumbling clouds of cooler gases, the chromosphere. What follows?

From Kirchhoff's first law (second paper); "All solids, liquids and gases under great pressure project continuous spectra." The spectrum of the photosphere is continuous. By Law III, (eighth paper), "All modes of matter when vibrating at their own rates absorb the same waves they emit." Thus the cooler layers of gases above the carbon envelope, yet hot enough to vibrate at their own rate, absorb, quench and destroy the motion of all waves sent up from below, and these cannot reach the earth. All waves so destroyed leave empty places in the spectrum, which black spaces are the Fraunhofer lines.

If now the moon crosses a straight line joining the centers of the earth and sun, at such a distance, from the earth as to

"fit" the sun, the entire disc will be cut out, leaving the carbon layer, the chromosphere or the layer of permanent gases above it, together with all other clouds and layers, and, lastly, the corona in plain sight for the few minutes of total eclipse. Within two seconds before the exact instant of totality the following side of the moon, just going before the sun's disc, will cover, and two seconds later the advancing side will also cover the carbon ring around the sun, cutting off its brilliant light. What happens from the laws of Kirchhoff? The reversing layer that caused the Fraunhofer dark lines will now emit bright lines of its own, and these bright lines flash out with great brilliancy through the whole length of the spectrum and the glorious sight will be on display two seconds or until the edge of the moon covers this layer also and cuts off the brilliant scene. This is the flash spectrum, and a spectroscopist will journey to the ends of the earth to see it.

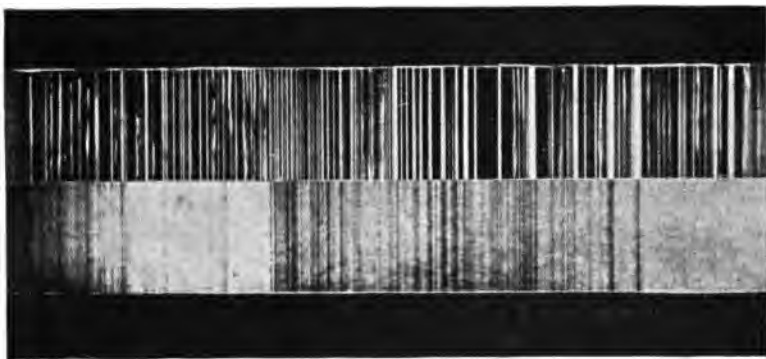
The flashing spectrum was first seen by Professor Charles A. Young at the total eclipse of the sun in Spain on December 22, 1870. When the moon had almost hidden the sun, the black lines were still visible, but at the exact moment of second contact, when totality occurred, he saw the usual black line solar spectrum disappear when:

"All at once, as suddenly as a bursting rocket shoots out its stars, the whole field of view was filled with bright lines, more numerous than one could count."—Young.

Therefore, Kirchhoff's law was actually proven to act on the sun as well as in the same experiment in terrestrial spectroscopic laboratories. The flash has been seen at subsequent eclipses and lines mapped.

Cut 41 is the wonderful flash spectrum secured by Mr. J. Evershed, at Talni, India.

What height of human skill and trained work was required to take this photograph at once the carbon ring was covered and before the rapid moon had time to encroach upon the reversing



Cut 41. Flash and Cusp Spectra Compared. Ultra-Violet Region L. 4100 to L. 3350. Enlarged Four Times From Negatives Nos. 3 and 1.

layer above! Thus Mr. Evershed had four complex instruments before him, all having to be manipulated with extreme accuracy; yet he secured thirteen photographs in one and one-half minutes. The nervous strain is severe, but the body is an abject slave to will. Cut 41 is Evershed's spectra, the lower being the ordinary spectrum an instant before totality, while the upper is the flash or reverse spectrum caught on the rapid plate one-half second later. All the black lines in the spectrum below are reversed, changed to bright above. They coincide end to end—they are direct lines from the gases of the chromosphere. These lines are from glowing iron, hydrogen, calcium, magnesium, helium, titanium, possibly silicon and carbon, with others; in all, fifteen modes had their lines changed in this memorable flash. It will be seen how intimate is the association of iron and hydrogen in the solar gases; a great fact that will be noted under the head of cosmical and stellar evolution, later.



Cut 42. Thwait's Graphs of Solar Eclipse. Exposure Upper $1\frac{1}{2}$ Sec.,
Lower 9 Sec. at Talni, India. Jan. 22, 1898.

Cut 42 is that of two photographs of the eclipsed sun and its corona, secured by Mr. Thwait, at the same time. The upper is an exposure of one and one-half seconds, the lower nine seconds, showing much greater extension of that mysterious crown, the crown of the sun.

XV.

HALE'S SPECTROHELIOGRAPH.

"He plants the eye of Surya in the sky, and disperses the delusion of darkness."—Rig Veda, V. 40.

"Bright-haired, white-footed steeds draw him along his ancient path without dust, and built secure, the golden-handed bounteous sun."—Rig Veda. (Primeval Aryan).

This remarkable instrument devised by Professor George E. Hale, now of the Yerkes Observatory, takes accurate graphs of the finer details of the apparent surface of the sun. Not only these, but the photosphere, chromosphere and the prominences can be graphed on any clear day without waiting for a total solar eclipse. This invaluable apparatus takes the place of an eclipse for all purposes, except graphing the corona. Knowledge of the sun was greatly augmented by the invention of this method of solar work and the thanks of the astronomers of the earth have already been rendered to Professor Hale. Its principles ought to be understood by all who admire the sun.

Cut 43 is a graph of the heliograph as it appeared in Kenwood Astrophysical Observatory in Chicago, before Professor Hale went to the Yerkes Observatory at Williams Bay, Wisconsin. It is attached to the lower end of a twelve-inch equatorial telescope, the same as the telespectroscope on the eye end of the Lowe telescope (Tenth Paper, cut 23). The entire disc of the

sun is cut off before the slit by a circular plate of metal, taking the place of the moon at eclipses. The plate is just large enough to fit or cut out the sun and its photosphere, leaving the chromosphere alone and the explosions entirely around the circumference in plain sight. And Hale, by a most ingenious arrangement of double slits, photographs them all at the same time; then he removes the metal plate and photographs the sun to fill up the



Cut 43. Hale's Spectroheliograph.

circle, thus securing records daily of all phenomena that may appear on the disc, and in the surroundings except the corona. He has taken many hundred graphs. These fill the minds of solar physicists with awe and wonder at the complexity of the sun.

The sun's photograph after the iron plate or screen is removed, is not taken at once, but is built up by successive narrow strips of photograph secured through a movable slit that slides

across the image of the sun. The effect is as though a complete graph of the sun could be taken at one instantaneous exposure, for not only is the disc shown with minute details, but the chromosphere and explosive prominences.

In cut 43 the first slit is seen at 1, where it may be placed radially or tangentially to the solar image as shown in Chapter X, cut 25. This slit in the Kenwood heliograph is $3\frac{3}{4}$ inches in length, and its width can be varied. It is mounted on steel balls so it can be moved easily across the image of the sun, in the plane of dispersion due to the grating. The light from the sun passes through the slit at figure 1, falls on the grating in its box at 3, is dispersed into a spectrum and reflected to the slit, just under the sensitive plate in its holder at figure 2. The slits at figures 1 and 2 move in opposite directions, with the almost incredible effect of building up a photograph. In graphing faculæ the slit upon which the solar image falls is 1-500th of an inch wide. This slit moves at right angles across the image just below figure 1—say to the left; then the slit just below the plate-holder at figure 2 moves to the right, the only light falling on the plate at any one instant of time being a thin line, an image of the slit. To make the motions of both slits coincide in exact time, both slit plates are moved by the same power which is due to water coming in from a pressure through the rubber tubes (4, 4). One pipe leads to the top of a cylinder (5), which contains a piston actuating both slit-holders. Since the same pressure of water moves both slits, the motion is synchronous, and the solar image is graphed with equal exposure for each minute portion. Hence a homogeneous graph is made, and these graphs have elicited the admiration of all scientific men.

The arrangement here described is for graphing the disc with its faculæ and spots; but if the prominences and chromosphere only are to be taken, a circular disc of iron just large enough to fit the two-inch image of the sun is placed about where

the figure 1 appears. This cuts out the solar image as formed by light coming through the end of the telescope at figure 6. Hale's spectro-heliograph is as record making in modern astrophysics as J. J. Thomson's discovery of corpuscles is to electricity and to the universe, and as Ramsay's slow but sure approach to the absolutely zero of temperature, is to the root and foundation of nature.

Clearly in the lead of all are his exquisite graphs of the faculæ, objects scarcely visible in the telescope without the heliographic attachment. These are inconceivably hot figures, arranged like blazing torches over the mighty disc of the sun. Their brilliancy is far more intense than in adjacent regions.

When all is ready with the apparatus, graphs are secured at the rate of one per minute, where before it required an hour to get a poor imprint of the sun. Evanescent, fleeting and transitory objects, explosions, currents, cyclones and hurricanes are at once caught in their impetuous turbulence and appalling fury, and instantly brought to a state of rest, like instantaneous graphs of a cataract where the troubled water seems to be without motion. A complete history of an explosion 40,000 miles wide and 200,000 high is written by its own light. White-hot masses many times larger than the earth are hurled to these heights with speeds ranging from 50 to 200 miles per second. Up and up rises the awful, seething mass, but every move is photographed.

There are now many heliographs in Europe, notably at Meudon and Potsdam, so that almost continuous records of the sun are written on permanent plates, especially since the graphic observatories in Sydney, Australia, have joined in the relentless conquest now on, the conquest of the mysteries of the sun.

Professor Charles A. Young saw the calcium lines in solar faculæ reversed in 1872. Hale now graphs them without difficulty. The H and K Fraunhofer lines, due to calcium at terrific heat, are reversed; that is, they become bright. And the inevit-

able hydrogen also appears. But reversal implies a force at work utterly beyond the brain of man to comprehend. The faculæ are so incredibly hot that if there are cooler gases above they are powerless to absorb the fierce light and thus cause a Fraunhofer dark line; or else the hot material is hurled up entirely through all inclosing layers, in the nature of white prominences, at such unheard-of heat that their corpuscles cannot vibrate at their own rate—too hot for that—so give the well-known continuous spectra due to all white light. But they are made of calcium, a leading constituent making up the geologic structure of the earth.

Young at first saw reversal of the lines merely, at or but slightly removed from spots. But Hale saw reversed lines on the disc far away from the penumbra of the spots. He conceived the idea because the reversed lines were so brilliant, even against the effulgence of the background of the sun's disc, that if this glare could be lessened the forms of the faculæ could be apparently isolated and graphed. This he actually accomplished with his narrow and synchronously moving slits and rapid plates. The now historic day arrived, January 12, 1892—Hale photographed the brilliant faculæ on the sun. These colossal areas of solar upheaval are now graphed at all hours of clear days with little effort.

The most noteworthy thing about faculæ, aside from their excessive brightness, is their enormous size. Spots large enough to take in thirty worlds like the earth were formerly thought to be large, but the "boiling-places," those seething cauldrons of the sun, are many times larger in area than the largest spots, and they show at all parts of the solar disc, while spots are mostly in equatorial regions. Human ingenuity seems to have reached its limit here, for the chromosphere and prominences on the edge of the sun are less brilliant than the hotter faculæ, and therefore require a longer exposure.

The circular plate of iron is held at figure 1 to cut out the sun, when the slit plates are both driven by the water with slow motion, giving long time exposure, going one way across the image. The iron disc is then removed, the sun's image again falls on slit plate, water flow is increased and the slits are moved



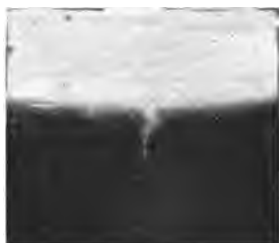
Cut 44. Photograph Made With the Spectroheliograph of the Kenwood Astro-Physical Observatory, Chicago, by Geo. E. Hale, Chromosphere and Prominences. May. 24, 1892.

with greater speed in the opposite direction across the field of view, giving short exposure, and this catches the faculæ and graphs them all in their true places. The entire sun, together with all phenomena, are thus portrayed—a thing thought impossible before Hale came into the intellectual arena of the world.

These famous graphs are imperfectly represented in cuts



Cut 45. Hale's Heliograph Showing White Hot Faculae.



Cut 46. Hale's Snapshot of Solar Prominence. March 24, 1892.

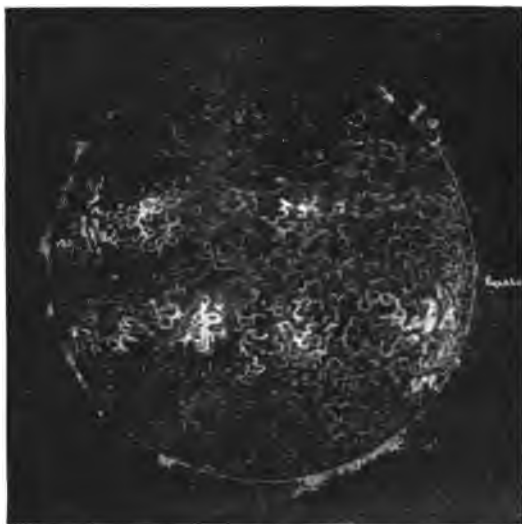
44 and 45. Cut 44 (large circle of sun) is where the slits make their first excursion across, with long exposure—several seconds—with the iron plate in place of the moon at eclipse; the chromosphere and a few prominences appearing. Cut 45 is Hale's photograph of the sun showing several white hot faculæ, and three or four prominences on edge. Cut 46 is a snapshot of an explosion on the sun. Nearly all the wonderful details of the sun, as seen on the original negatives, are lost when transferred to paper.



Cut 47. Hale's Photograph of Solar Prominences, Showing Rapid Changes.
Nov. 15, 1892.

Cut 47 is a series of photographs taken November 15, 1892. Intervals between graphs 1 and 2, five minutes; 2 and 3, twenty-five minutes; 3 and 4, fourteen minutes; 4 and 5, one minute; 5 and 6, two minutes, showing rapidity of changes in prominences.

He also made a most remarkable composite drawing from four original plates. They were projected on a white screen by a



Cut 48. Hale's Composite Graph of the Sun.

lantern, thin paper being placed over the image and traced with a crayon. The four pictures are thus superposed. Two of the negatives showing prominences were taken at 9:15 and 9:59 a. m., and two showing faculæ were exposed at 9 and 9:06 a. m. Hale placed a blue glass in front of the slit to absorb some of the light of the photosphere, thus making the faculæ more distinct.

Here is a quotation from Professor Hale: "I have elsewhere remarked on the great size and extent of the faculæ as shown on photographs taken with the spectroheliograph. The negatives made with the blue glass absorbent, however, show that my estimates have been too small. Faculæ hitherto invisible are now seen dotting the surface of the sun from pole to pole. The faint faculæ do not appear to be separate and independent phe-

nomena; for over the whole surface of the sun they seem to be connected like the meshes of a net, though the forms of the inclosed spaces are very irregular."

It is hoped that some of the marvelous network can be seen when cut 48 is transferred to the printed sheet.

And now a ceaseless record of the sun is being made in countless heliograms throughout the world.

XVI.

SOLAR SPOTS.

"The sun rises out of life and sets into life."—Brihad Upanishad, vi-2 (Hindu).

"The light of the sun is the soul that moves or rests."—Rig Veda. B. C. 1500 Aryan.

"Thou in the form of sunbeams, preservest the world."—Vishnu Purana (Hindu B. C. 800).

"The sun sinks in the ocean, and azure-hued vapors arise; it is Nature's incense of devotion perfuming the skies."—Anwari Palinodia, Persian Scriptures.

These have been watched with ever-increasing interest since the invention of solar eye-pieces for telescopes and with renewed activity since the appearance of the solar spectroscope and spectro-heliograph. They are periodic. The average period obtained from many years' observation is eleven years and two months. Sometimes it is near thirteen, and at others near ten years. The maxima occurred in 1848, '60, '70, '81, '92 and another is due in 1903.

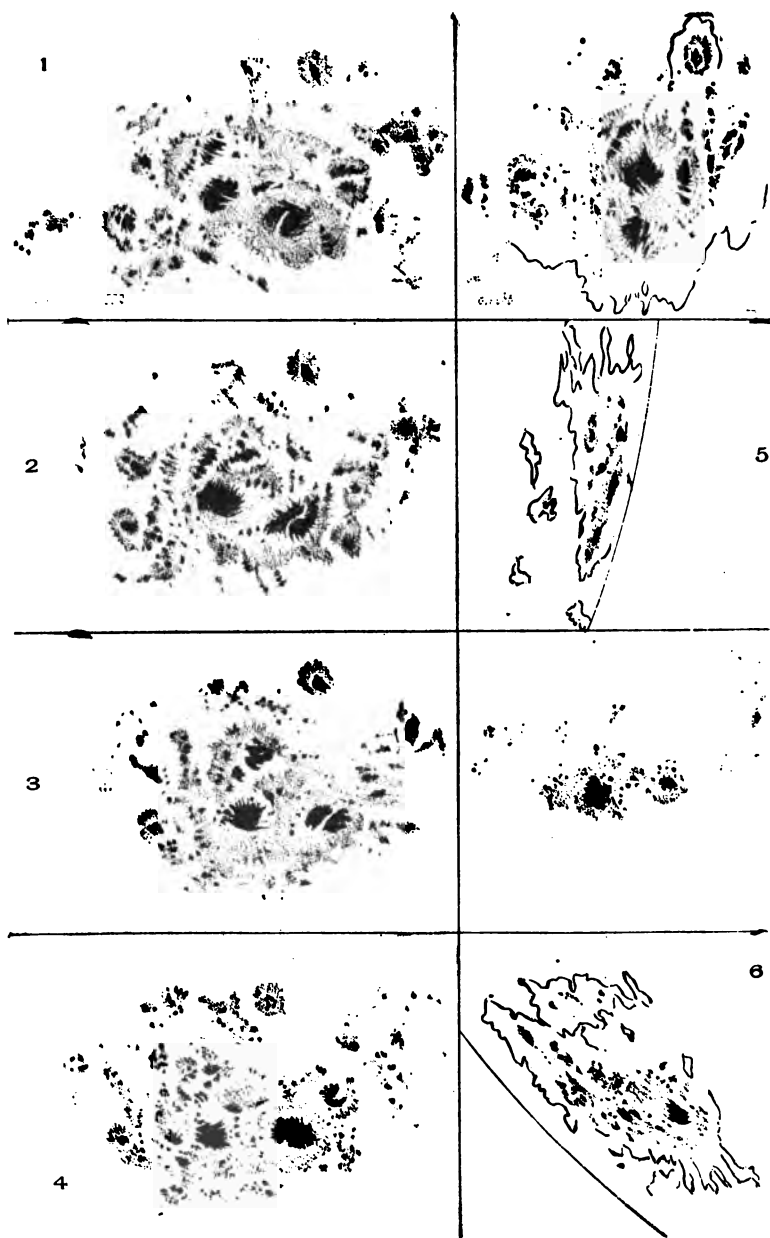
This period of eleven years and two months is composed of two unequal parts; there are on an average six years between maxima and minima, and five years from minima to maxima, thus the period of increase is shorter than decrease.—Angot, *Aurora*, page 94.

A normal spot is composed of the dark umbra in the center and this is surrounded by the penumbra, somewhat lighter colored and in the center of the black umbra still blacker dots are seen called nucleoli. With high-power telescopes the umbra is at times seen covered with filmy vapors, apparently floating over from the photosphere. A majority of spots are, however, so irregular in shape that they are not the typical form. The umbra looks black in the telescope, but Langley compared the light from the nucleus with the surface of liquid Bessemer steel in a blast furnace, and found that the black center of a sun spot is brighter than a calcium light, and its blackness is due only to contrast. Astrophysicists are now nearly all agreed that spots are depressions in the photosphere, filled with cooler and therefore heavier gases. And when they pass the edge of the disc, owing to rotation of sun, they are seen at times to be deep enough to cut out a notch.

The penumbra is composed of long, separate filaments or streams of intensely hot matter from the adjacent photosphere, pouring over like a gigantic cataract. This process in time usually fills or submerges the spot.

They are not deep, ranging from 500 to 2,500 miles, seldom so deep as the latter. Minute spots are in diameter from 500 to 1,000 miles, while others are seen almost daily, at maxima, in diameter from 40,000 to 60,000 miles. At times the penumbra has been measured, showing width of 150,000 miles.

The actual beginning of a spot is rarely seen; they commence in a minute black speck and rapidly expand. The penumbra does not appear until the umbra is complete. If the spot is caused by an upheaval it breaks into separate fragments, all of which keep up with the turning of the sun on its axis. When a spot is about to come to an end, a jet or tongue of white hot matter, usually the end of a facula, starts to cross the fearful chasm. These are termed bridges. They rapidly grow wider,



Cut 49. Sun Spot, Showing Changes at 1, 2, 3 and 4. 5 is a Spot and Facula on Western Limb and 6 on the Eastern.

others start, and then there is a continual flood of hot material from the photosphere, and this bends or pours down the penumbra to the yawning umbra, and the spot vanishes, an exceedingly brilliant facula taking its place.

Cut 49, figure 1, is a twisting spot drawn by an observer February 11, 1892, at the last maximum. Figure 2, is February 12th, 3, 13th, and 4, the 14th. Cyclonic motion, bridges, filaments and jets are well seen. The sun turns from west to east, opposite to the motion of the hands of a watch. Figure 6, cut 41, is a large spot coming on east, and figure 5 is the same spot going off west after an interval of 12 3-4 days if the spot is somewhere near the equator. For the equator revolves in less time than the surface of the sun in either latitude. Thus by watching a spot in latitude 45 degrees the spot will require 12.63 days to cross, that is, the sun revolves in $25\frac{1}{4}$ days at the equator and $27\frac{1}{4}$ days in latitude 45 degrees. The sun is not solid, therefore, for all parts of a solid globe revolve in the same time.

The cause of variations in solar rotation is not known, but vast currents in the equatorial regions seem a plausible theory, these flowing east, or currents in both latitudes flow west.

The spots in figures 5 and 6, cut 49, are surrounded by the outlines of immense faculæ. Some spots appear and vanish in a few hours; others in a few days. Many make one or two circuits with the sun, and one was seen to make 18 revolutions before the faculæ and torrents from the photosphere finally conquered. Spots are confined to two zones 35 degrees wide between 5 and 40 degrees in either north or south latitude. None have been seen near the poles, while faculæ are shown in Hale's graphs near both poles. The corona also stands out from both solar poles.

In cut 50, a spot coming to an end is shown, with many bridges starting across in all directions, while cut 51 is a new spot, with only one jet starting in the lower portion. The



Cut 50. Sun Spot Coming to an End. Bridge Crossing Umbra.



Cut 51. Sun Spot Just Formed. No Bridges.

dots on each cut, 50-51, are true dimensions of the earth. Veiled spots are seen, large submerged areas, covered by thin cloud-like forms, as though they could not appear clearly through them, and these are usually enclosed round about by white-hot seething faculæ. One at the telescope, viewing an active spot, cannot actually see the jets move, any more than the motion of the hour hand of a clock, but going away and returning in a half hour, the rotary displacement is noticed at once, or straight line advance, if a bridge or jet is on the way across.

Many theories have been given to explain solar spots or depressions, but none are free from objection. Faye thinks they are terrific cyclones twisting up matter like a waterspout at sea; this cools, falls back denser and shuts out light from below.

Secchi maintains that violent explosions occur around the place where a spot is to appear, drawing vast quantities of matter laterally, and allowing the undisturbed portion near the center to sink into the cavity, and then the portions hurled up, fall into this depression, cooler from their journey of a hundred thousand miles or more. Professor Charles A. Young, an authority on solar matters, advocates this hypothesis.

At first, the "motion of the center of a spot is inward not outward."—(Young.) This is known, for the spectroscope at once reveals whether a source of light is advancing or receding. The spot spectrum shows the solar lines, but much widened, and the terrific vortex of hydrogen presents the lines bright in some cases. Therefore there is but little absorption of hydrogen in the umbra. But approach of hydrogen with the unheard-of speed of 300 miles per second has been seen at or near the edges of the spots, while a downrush was noted in the center.

The mystery of sun spots is by no means settled, but this ascent and descent presents a most impressive picture of the grand scale upon which the circulatory gases of the solar disc take place.



Cut 52. Professor S. P. Langley's Magnificent Sun Spot. (Drawing.)

Cut 52 is one of the most magnificent drawings of a sun spot ever made. The marvelous tongues, filaments, jets and spray over the black abyss are beyond comprehension. All over the adjacent regions are shown the "rice grains" and rough granulations always seen on the sun. This superb delineation was made by Professor S. P. Langley at Allegheny, Pa., Observatory. It is still admired by solar physicists throughout the world.

NOTE.—Readers of this series are specially requested to study and fully understand the properties of that wonderful space, the magnetic field, before the next paper appears. It will be on the effect on the earth caused by these jets across sunspots. The effect is magnetic, therefore the electro-magnetic field should be comprehended. Any work on electricity or higher physics will give the explanation.

XVII.

JETS ON THE SUN—THEIR EFFECT ON THE EARTH.

In the sky's framework she has shone with splendor
The goddess has cast off the robe of darkness,
Waking up the world with ruddy horses.
Upon her well-yoked chariot Dawn is coming in.

—A Rishi's Hymn to Dawn, Rig Veda (1-113).

And rival tempests rush amain
From sea to land, from land to sea,
And raging form a wondrous chain
Of deep, mysterious agency.

—Michael in Goethe's Faust.

And other suns perhaps,
With their attendant moons that will descry,
Communicating male and female light
Which two sexes animate the world.

—Milton.

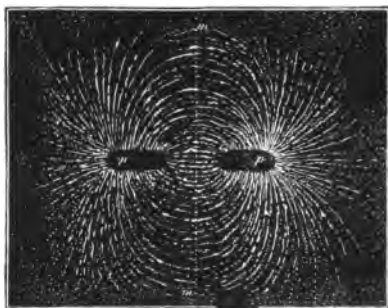
The immediate effect is now known to be electro-magnetic. The results of a century of observation all point to this conclusion. When a mighty tongue of white hot matter darts across the abyss of a large spot or cavern on the sun, the equilibrium of the earth's magnetic field is disturbed and the effect is a magnetic storm. The needles of magnetographs throughout the world shiver, tremble and oscillate. The vibrations take place on opposite sides of the earth, the impulse not requiring time that can be measured, to pass from the side of the earth nearest, to that most distant from the sun, whether through or around it.

These magnetic instruments are self-recording, so no electro-magnetic wave from the sun can strike the earth without making its own record in the electro-magnetic observatories. These are separate buildings and the framework is bound together with copper nails, no iron being allowed near the delicate apparatus. The oscillations of the needles are recorded by automatic photographic mechanism driven by clocks, and are complex in detail. They have rendered valuable knowledge of pulsations on the sun.

After three centuries of investigation from Gilbert to Tesla, this most wonderful space is still the admiration and inscrutable mystery of all who study that vast science, electro-dynamics. Power is cut out of this space, and the hurrying waves are caught, dragged from seemingly void areas and chained to servitude in the electric light and railways. But the sun is electro-magnetic and waves carrying power, beat and surge against the earth. A magnetic field is space surrounding a magnet. This space may be filled with air, wood, stone, glass, or may be a vacuum, but the waves are not quenched. They flow through all these. A freely suspended magnet in a magnetic field will move, and the earth's surface is surrounded by a magnetic field, which is acted upon by solar magnetic energy. A free magnet will place itself parallel to straight line of magnetic energy, or tangent to a curved line. For all magnetic energy round a magnet moves in lines.

Cut 53 shows two poles and the resulting curved lines in the adjacent space. The black square represents a plate of glass lying on the poles of a vertical U magnet. Iron filings are dusted on the glass, when the waves or lines of magnetism at once arrange them into the curves, the curvature being caused by mutual attraction of the poles. If one pole is used, the iron particles will be arranged into straight lines radiating in every direction. Suspend a sewing needle by a silk fiber in the field (cut 53) and it will at once place itself tangent to the curves and come to rest. But let the field be disturbed—that is, become stronger

or weaker—and the needle will move. This is a magnetic storm. And when a jet is hurled across a spot on the sun the disturbance reaches the earth in the same time that light does—so radiance traveling 186,000 miles per second—reaches the earth in eight minutes nineteen seconds. The terrestrial field responds at once and every magnetic needle on earth begins to swing, the photographic plate recording every beat, and the clock records the time, so the history is complete. And here again it is impossible to refrain paying another tribute to the invaluable aid of photog-



Cut 58. Magnetic Poles and Field.

raphy to science. But when the times recorded by the clocks are reduced for differences in longitude, the absolute time of storm is the same for all.

MEMORABLE MAGNETIC STORM, NOVEMBER 17, 1882.

This was one of the most violent on record. On November 15, 1882, after an interval of cloudy weather, a view of the sun was secured. An enormous spot was at once seen already advanced on the eastern solar limb 24 degrees. It was in a state of excessive turbulence, since none of the jets were straight, but were twisted, crossed and contorted in every shape. The edges

of the chasm were notched and indented, while the umbra was traversed by bridges, filaments and photospheric debris. The spot seemed to be in rotation, confirming the theory of vortex or whirlpool motion, for striæ, granulations and tufts of incandescent matter were strewn about the inclined or depressed sides of the penumbra as though impressed with the centrifugal tendency of rotary motion.

Clouds again obscured the sun until 8 a. m., November 19th, when the sky became clear and remained so four hours, during



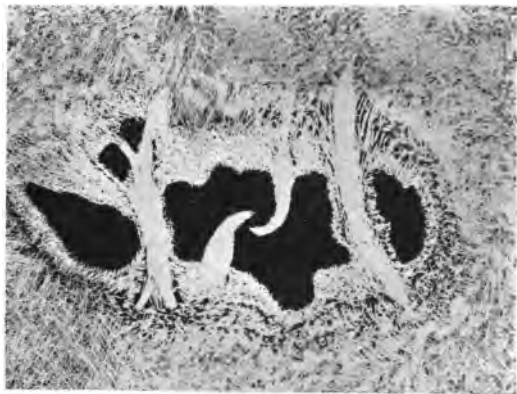
Cut 54. Sun Spot, 8:30 A. M., Nov. 19, 1882. Jets Starting From Opposite Sides.
(Drawn by the Writer.)

which the drawings (cuts 54 and 55) were made with eye at telescope, a fine six-inch Clark equatorial, with prismatic solar eye-piece.

The disruption of the spot was almost complete, since the 15th. The black umbra had become broken into four masses (cut 54, drawn at 8:30 a. m., November 19th), when two tongues were seen starting across from the lower side. At 9:30 a jet of inconceivable brilliancy started over the abyss from the upper side, as shown. The solar prism was covered with black glass to

protect the eye, yet this jet at terrific heat was too bright to look at for more than an instant after it had well advanced, but at the starting was not so brilliant. It became brighter as it moved, a thing not understood. The lower jet also advanced, and the awful tongues grew brighter and brighter.

At 10 a. m., or in half an hour, the jets were as shown in cut 55. They had approached so that only a narrow strip of black remained between. They curved toward one another, and seemed at the point of striking in collision. It was watched with



Cut 55. 10 A. M., Nov. 19, 1882. White Hot Jets About to Strike Together.

intense interest with pencil in hand, ready to depict the scene, just to occur, when a cloud came across the sky and obscured the wondrous spectacle. The disappointment was acute, but one common to astronomers. On the next day the two jets combined into one wide bridge.

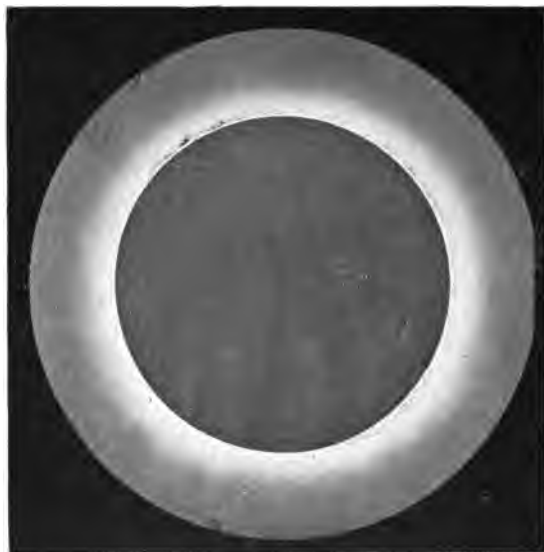
The spots shown in cuts 54-55 are merely the central portions; there were 108 smaller spots around the edges of the penumbra, the interior edge only being drawn,

And on the other portions of the sun twenty-three other spots were also counted. But the daily press of November 17th was burdened with accounts of widespread magnetic disturbance, in some places suspending telegraphic manipulation. The area of turbulence filled that great quadrilateral from New York to Yankton, Nashville and Winnipeg. In Milwaukee the carbons in the electric lamps were lighted, rendered incandescent by currents of electricity flowing in on the wires. At other points, switch-boards in telegraph offices were set on fire and keys melted on the apparatus, while electric balls were seen hovering on the telegraph in Nebraska. The Atlantic cable was in a state of unrest and more or less disturbance was noted in Europe. This now historic spot was 38,000 miles wide and 87,000 long, the mean of several measures. The jet at the upper part of cuts 54-55 therefore traveled 19,000 miles in thirty minutes.

On October 7, 1880, Professor C. A. Young saw an outburst which hurled matter vertically to a height of 300,000 miles, but the jet of November 19, 1882, was horizontal across the spot. On August 5, 1872, he also saw a disruption that cast up white-hot matter at a rate of 120 miles per second, much faster than horizontal speeds. On writing to Europe he received reply that British magnets were in agitation.

Including 1882 there were three great magnetic storms, and these coincided almost exactly with the maximum disturbance in the sun spots. However, great spots have been seen on the sun without magnetic unrest on the earth, and conversely, storms without spots, possibly due to prominences not seen.

The first and now classical observations of these phenomena were made September 1, 1859, by Messrs. Carrington and Hodgson in England. These two observers were many miles apart, but both happened to be observing the sun at the same time. They simultaneously saw two objects of intense brilliancy, 8,000 miles in length, 2,000 in width, and 12,000 miles apart, suddenly



Cut 56. Total Solar Eclipse. Short exposure Showing Gases Near the Sun Only.

appear on the edge of the umbra of a gigantic spot. The brightness of these was five or six times that of the adjacent regions of the sun. They both moved side by side over the spot, 36,000 miles in five minutes, and vanished. These were detached masses and did not appear as continuous jets. A great magnetic storm occurred that evening on the earth, and also a magnificent display of the aurora borealis.

XVIII.

TERRESTRIAL INFLUENCE OF SUN SPOT ACTIVITY.

"Approach, O Vishnu! enter thine own body, the eternal ether. Thou art the abode of the worlds."—From Ramayana, vii.

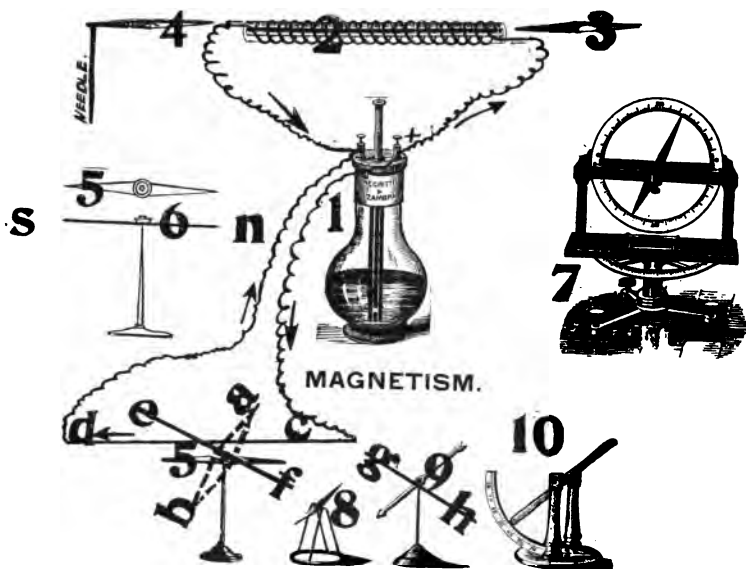
Not only do jets, darts and bridges across cavernous spots upset the equilibrium of the earth's magnetic field, thus causing balanced magnets to swing, but they disturb the telegraphs of the world, and also cause displays of the aurora borealis, and at times austral as well.

Coincidence of auroral splendors and solar spot action is well marked, and periodicity is clearly established. But the aurora is known to be electro-magnetic. This term now occurs so often in scientific literature that it ought to be understood by all who wish to know about cosmical physics.

This is the conservation of magnetism from, or by means of electricity. Magnetism is thought to be a vortex in corpuscles, and if the vortex can be suddenly fixed while in the midst of its motion, like an instantaneous graph of falling water or of a dynamite explosion, the result will be a permanent magnet.

Steel permits the cessation of motion and fixation of corpuscles within its particles while iron does not. And steel is iron with the addition of a minute quantity of carbon, one or two per cent only. The mystery hovering round about carbon lies at the root of nature, for the chemical union of carbon with iron renders

the compound susceptible to the most inscrutable wave-motions, oscillations and pulsations, surging through the universe. How can we clutch corpuscles and chain them to ordinary chunks of matter usually called atoms, and thus convert them into permanent magnets?



Cut 57. Electro-Magnetic Apparatus. The steel needle 3 passed through the electric coil (2) and becomes a magnet as at 4.

This process is shown in cut 57. No. 1 is a zinc and carbon cell separating electricity from matter and sending it out on the positive wire, whence it returns to the negative pole. At 2, the wire is coiled around a glass tube, while at 3 is a thin piece of steel having no magnetism, for it will not lift up iron dust. Close the battery circuit, the wire becomes a center of electrical energy. Pass the steel through the tube, take it out at 4—a marvelous

change has taken place—it will hold up a sewing needle, as shown! This has remained the wonder of all electricians from Faraday to Edison. What mind is able to fathom this mystery?

Every wire forming a connection between the terminals of a source of electricity is surrounded by a magnetic field. The magnetic energy here passed through glass and filled the tube with its lines. The steel cut them out and fixed their potency in its particles, and became a permanent magnet.

The steel needle (4) has also acquired a remarkable property in relation to electricity, for if it is placed upon a pointed support, as at 5, and if a wire (C D) be held over it, then will the needle (5), turn in the direction (A B) if the battery circuit is closed.

Law. A magnet free to move places itself at an angle with a flow of electricity.

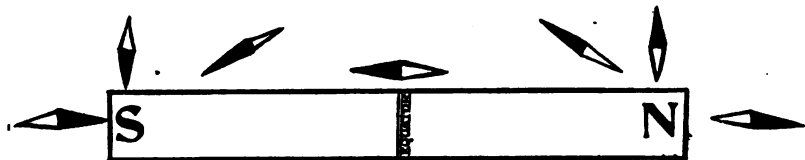
This is deep seated in nature, and is the cause of magnets moving themselves at angles to currents in or on the earth; that is, to point north, for if the steel (4) be placed at 6, in any position, it will turn to point north if left to itself. There must be a current flowing from east to west under it, and since the earth turns from west to east, the sun appears to move from east to west, and the sun causes the earth currents. If the sun is torn and tossed by storms, disturbing its magnetic field, the currents induced in the earth at or near its surface will vary, and this will vary the potential of the earth's magnetic field and cause magnetic storms.

Passing of the steel from 3 to 4, through the electro-magnetic field of force in the tube, and appropriation of magnetic energy by the particles of metal by the capture of corpuscles, is electro-magnetism. It pervades nature.

If the needle (6), anywhere north of the equator of the earth be suspended as shown, without making its south end heavier than the north, then the north end will dip as in 8, 9 and 10. Additional steel is therefore put on the south end to counteract

this tendency, if a horizontal needle is wanted. Dipping needles are always inclined by an angle equal to the magnetic latitude, or distance of the needle from the magnetic equator of the earth.

In 10, a scale is attached with degrees marked so this angle can be read in any place on earth, while 7 is complete dip circle, as used in all the magnetic observations. South of the earth's magnetic equator the needle would point the other way—that is the south end would dip, and the north rise, being horizontal only at the equator.



Cut 58. Magnetic Needle Carried Around a Magnet.

This may be seen in cut 58, where a bar magnet is shown, with a needle near it, in several positions. It will be seen that the white end of the needle is opposite the plus pole of the magnet and the black end adjacent to the minus pole. If, therefore, a magnet, hung on a pivot, be carried from the north magnetic pole of the earth south across the equator to the south pole, and past that round through the equator to the north pole again, it will make one complete revolution. In cut 58 the needle is shown as having made half a revolution, having been carried half way around.

When a colossal tongue of white hot matter is shot across a sun spot, the needle 5, in cut 57, will swing to either a, b, or e, f, with violence, while the needle 9 will vibrate to g, h, in a vertical plane. This is a magnetic storm.

RECORD OF MAGNETIC STORM OF JULY 16, 1882.

Made at Terminals, New York and Boston.

Times. h. m. (p. m.)	Strengths of	
	Currents in Milli-Amperes.	Pressures in Volts.
12:37.....	27	100
12:39.....	32	118
12:39½.....	48	177
12:40.....	44	163
12:40¼.....	144	492
12:41.....	68	252
12:43.....	20	74
12:44.....	15	55
12:45.....	19	70
12:46.....	14	52

Resistance of line wire, 2,700 ohms.

Between New York and Providence, R. I.

P. M. h. m.	Currents	
	Milli-Amperes.	Pressures Volts.
12:05.....	9	20
12:07.....	42	113
12:12.....	4.3	12
12:15.....	.8	2
12:29.....	280	644

This is a most impressive record. Thus, from New York to Boston, the line resistance was 2,700 ohms, yet, when terminals were put to earth, the current on the wires due to the storm was strong enough to register 133 milli-amperes (thousandths) at the height of the upheaval on the sun. And between New York

and Providence, two hundred and eighty-thousandths of an ampere, with a pressure of 644 volts. But on the evening of July 16th a grand auroral display occurred, and a vast sun spot was in turbulence in high south solar latitude and near the western limb. The telegraphs had been disturbed from New York to Chicago and Omaha during the entire week before the culminating storm and aurora.

XIX.

THE AURORA AND SUN SPOTS.

"Thanks to the light of the rising day, to the dawn longed for, which puts an end to the anxieties and terrors of the night."—Vedic Hymn to the Dawn.

"At times there are fire-glows, sometimes fixed and persistent, sometimes flitting. There are Bothynoe, when as within a corona, the fiery recess of the sky is like a cave dug out of space. There are Pithitæ, when the expanse of a vast and rounded fire is either carried about or glows in one spot. There are Chasmata, when a certain portion of the sky opens, and gaping, displays the flame as in a torch. The colors of these are many. Certain are of the brightest red, some of a flitting and light flame color, some of white light, others shining, some steadily, and yellow without eruptions or rays. Under Tiberius Cæsar the cohorts ran together in aid of the colony of Ostia as it appeared in flames, when the glowing of the sky lasted through a great part of the night, shining dimly like a vast and smoking fire."—From the Latin author Seneca, *Questiones Naturales*. Lib. I. C. XIV., Capron's Trans.

"About this same time Antiochus prepared his second voyage into Egypt:

"And then it happened, for the space of almost forty days, there were seen horsemen running in the air, in cloth of gold, and armed with lances like a band of soldiers.

"And troops of horsemen in array, running one against another with shaking of shields and multitude of pikes and drawing of swords and casting of darts."—Book of Maccabees, II, Chapter V, 1, 2, 3.

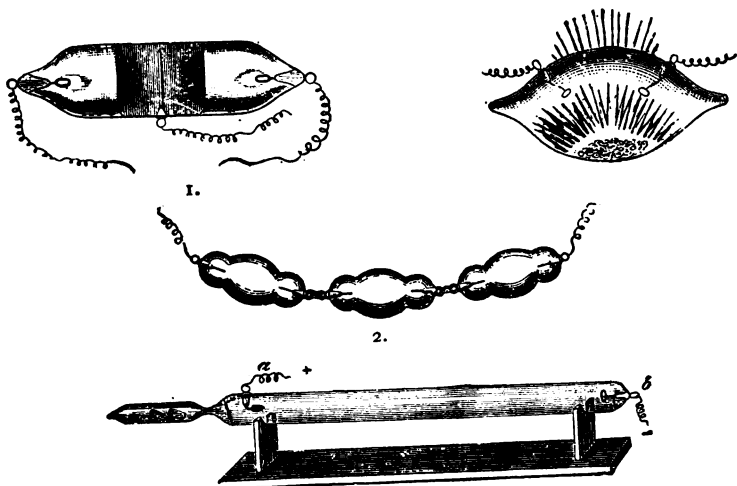
"There was a bloody appearance of the heavens which seemed like fire descending on the earth, in the third year of the 107th Olympiad and a light seen in the nighttime equal to the brightness of day."—Pliny, Lib. I, C. xxxiii.

The aurora should be studied with care by means of every resource known. An aurora is the visible effect of obscure undulations from the sun, that source of waves, as they come dashing on the earth with a speed of 186,000 miles per second. It is

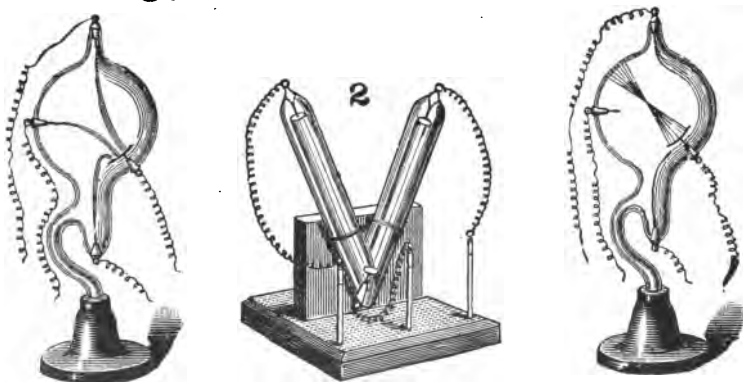
known that a wave of light is a wave of electro-magnetic disturbance. In a six-months winter, say at the north pole of the earth, the sun is far south of the equator, and none of its rays can shine on the earth's northern pole. But the aurora is very brilliant. It shows many colors, and these flash and glow with rapid variations. The light, although it is caused by the sun, does not come direct, but is caused by the turbulence set up in the earth's magnetic field by electro-magnetic upheaval on the sun. The field of the earth is "tuned" for that of the sun, as are coherers in sympathetic telegraphy and telephony. The aurora is known to be electrical, for magnets and compass needles on ships are always affected.

No magnet can be placed near a "current" of electricity, or a static charge without making oscillation. If a bar magnet be broken into two portions, each becomes a magnet with plus and minus poles. If each piece be again broken, the result is four magnets; if each of these is divided, there will be eight magnets, and so on, and there will be as many magnets as there were gross atoms of steel in the original bar. For each particle has an equator and poles, and is animated by a closed circuit of magnetic energy. This is Ampere's concept, and every magnet behaves in accordance with it.

In cut 59 there appear seven Crookes' wonderful vacuum tubes, with which he approached the doors of a labyrinth leading to the very confines of matter. The air has been pumped out so that only a very minute quantity remains. Thus while the pressure on the outside is fifteen pounds of air per square inch, it is only a minute fraction of this within. The ends of fine platinum wires have been pushed through the sides of the tubes when the glass was white hot. Now connect the ends of the platinum wires to the terminals of either a static electrical machine, or an induction coil in action, all in a dark room. Instantly the tubes light up with supernal radiance. Their beauty is beyond description. The light oscillates with great rapidity; they glow and



CROOKE'S TUBES.

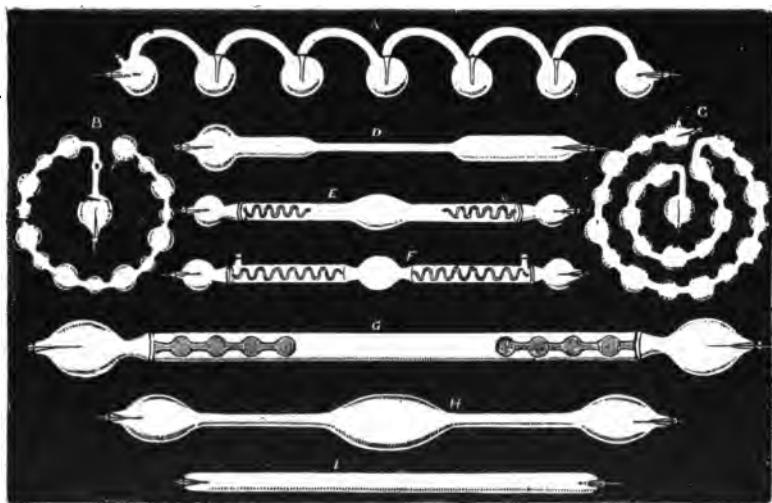


Cut 59. High Vacuum Tubes.

blaze, and their corruscations are the wonder and admiration of all who behold. They look and behave like the oscillatory discharges of the auroræ hung up above the poles of the earth. The writer has lighted these tubes hundreds of times with both sources of electrical oscillations, and always with the auroral effect. In the ruby tube, the imitation aurora is shown glowing under the action of high-pressure electricity; while the V-shaped tube, No. 2, looks exactly like the vertical streamers of a pulsating aurora. The other tubes are of great interest, especially in that vast region of research, molecular bombardment, and cannot here be explained without entering upon an elaborate treatise on modern electricity. Suffice to say that the phenomena on display in these tubes with varying rates of vacuity, are in that mystical place, the dim borderland between radiant energy and radiant matter, if indeed there is any boundary between, for Thomson's corpuscles and Crookes' electrons, although matter, behave like radiant energy. And mystery deepens, for both Crookes and Thomson came upon the same bodies smaller than atoms by different methods.

Cut 60 presents nine Geissler tubes. These have been exhausted of air by means of a powerful Sprengel mercury air pump. Then they are filled with such gases as nitrogen, hydrogen, oxygen and the hydro-carbon series, and are then flashed by high potential electricity and held before the slit of the spectroscope for analysis of their radiant energy. No two gases vibrate in the same rates and therefore no two give the same colors. But all rates and colors ever seen in auroral streamers, columns and curtains are shown in rapidly oscillating electrical discharges in these high vacuum tubes. No new mode is seen in the auroral light.

Nine lines have been seen in auroral spectra, but not more than seven at once. The brightest is in the yellow-green, but in one aurora Perry saw the red brightest, in a curved streamer. A magnetic storm was raging at the time, while Capron saw the



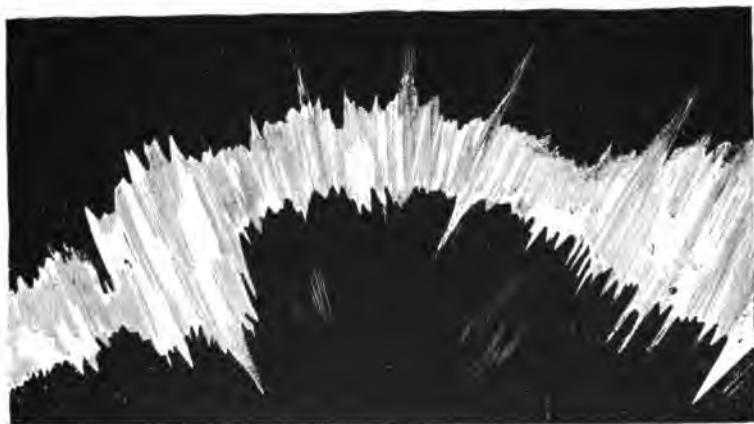
Gessler's
 Cut 60. Crooke's Tubes Filled With Hydrogen, Oxygen and Other
 Permanant Gases for Electrical Researches.

green-blue flickering in all parts of the spectrum of the same display February 4, 1872. The great aurora of April 9, 1871, was so brilliant that measures of its spectral lines could be made with micrometer, and nine were measured. In every aurora the green line is present, while the others vary with different apparitions.

The red line in the auroral spectrum is due to nitrogen, according to Vogel, and also the two others toward the violet. The third line in the spectrum of oxygen appears as the fifth in the spectrum of an aurora. Most of the lines are due to air and its gases. But iron lines appear in the spectra of auroral light and the mystery is how can iron vapor exist in air. Vapor is made of exceedingly fine particles, so fine that they are able to exist in the higher regions of the air against gravity for some time, or there is a continual precipitation of iron dust, at least during the period of an auroral display.

Nordenskjöld set up vertical tin tubes in the Arctic regions, and caught fine particles of iron from space. But iron is the most magnetic metal—and the aurora is an electro-magnetic disturbance.

Sounds have been heard at times of auroral displays, and ozone has often been detected by its odor. This can be made in the laboratory at any time by the action of electricity on oxygen. If the Crookes or Geissler tubes, when the electric pressure is pass-



Cut 61. Carl Bock's Aurora.

ing through them, be placed between the poles of a powerful electro-magnet, all the effects are intensified and the colors of the lights in the tubes can be changed to imitate the colors of an aurora by simply increasing or decreasing the strength of the invisible magnetic field in which the tube is placed.

Cut 61 is a drawing of a magnificent aurora of the arch and pulsating type. It was made by Professor Carl Bock at Por-

sanger Fjord, in Lapland, October 3, 1877. The sky background is green, with yellow in the streamers. The wonder about this aurora was that the arch remained at rest, while the streamers shot up in front with great speed and lateral undulation. It lasted two hours. The axis of the bow or arch was parallel to the magnetic axis of the earth.

XX.

AURORAL DISPLAYS.

"For before sunsettng chariots and troops of soldiers in their armour were seen running among the clouds, and surrounding the city." Josephus, "Wars of the Jews," book vi:5-3, on Vespasian, Siege of Jerusalem.

Aristotle, *De Meteoris* Lib. I, Ch. iv., describes the aurora as an "appearance resembling flame mingled with smoke."

Mathew of Westminster, in England, A. D. 555, says (*Annals of Phil.*, Vol. ix, p. 250): "Lances were seen in the air." In 1656 pyramids were seen in England in "*regionis æris*."

In Ireland a scarlet aurora was thought to be a shower of blood. All prodigies seen in the sky that were in motion, recorded in the history of the world, were due to auroral displays, aided by imagination. Auroræ seen just before battles were always seen to be legions of soldiers coming to engage in terrestrial war.

SELECTION OF SPACE WAVES BY THE EARTH.

This is all that is necessary for the earth to do, or man. The fountain is the sun and all waves of whatever length are electro-magnetic. For if the two ends of a wire are connected to the opposite poles of any source of electricity, the regions round about the wire instantly becomes saturated with magnetic energy. A piece of steel anywhere in this field will select some

of the waves, quench their motion, store the energy, and when the steel is removed it carries the energy with it. Iron cannot carry energy away from a field.

If the ends of two different kinds of metal be soldered together, and one of the ends be heated, while the other remains cool, a current of electricity will flow if the other ends are connected by a wire. The earth contains vast quantities of metals, for the specific gravity of the whole earth is much greater than that of any rocks on the surface layers. The center is particularly dense. There must be vast beds of unlike ores in contact not far below the surface, or, indeed, close to, or on the external sheet. These are warmed by the sun, and thermo-electric currents are set up. But a free magnet, either over or below a current, or anywhere near it, moves to make an angle with it. The stronger the current the greater the angle, until finally a right angle is reached. If the current varies the angle varies in exact ratio. And the magnetometers of the earth do actually change this angle every day. The thermo-currents flow from east to west, and magnets must point north and south to obey the law and make angles with them. The direction of magnetization of the earth is therefore roughly north and south. The auroral displays are nearly symmetrical with the magnetic poles and axis of the earth. And this axis is roughly parallel to the axis of the sun, while the axis of the earth's rotation makes an angle with the sun's axis of rotation. The sets of poles and axes are not coincident.

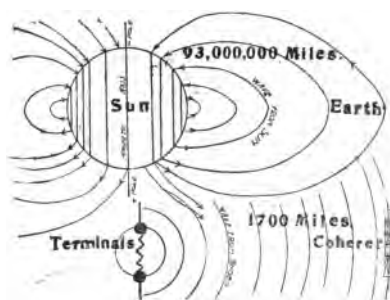
Thermo-electric currents are weak, and are only able to set up minute daily variations on earth.

THE SUN A SPHERICAL MAGNET.

Cut 62 is an inadequate sketch of Professor Frank H. Bigelow's exploration of the magnetic field surrounding a magnetized sphere. He finds the flow from plus to minus hemispheres, as

indicated by the arrows. Let the sphere be the sun, then to the extreme right is a minute dot, the proportionate size of the earth. It is being struck by a wave front of magnetic radiation from the sun, which disturbs the field.

Below the sun are shown two terminals of an induction coil used in wireless telegraphy and phony, in setting up waves. To the extreme right is the coherer, in a distant receiving station. It is also being hit by the same kind of wave-making impact on the earth. The wave makes the loose particle of metal between the knobs in the glass tube cohere into a wire for each dot and



Cut 62. Bigelow's Spherical Magnetic Field.

dash, and thus switch in a local battery. The process is cutting waves out of space.

The earth and coherer are both doing the same thing with the same kind of waves, known to be electro-magnetic.

The sun and the coil evidently do the same kind of work; that is, an explosion on the sun. The zig-zag between the knobs is lightning, has a pressure of 750,000 volts and length of 24 inches in the Los Angeles-Avalon space telegraph, and 42 inches in the distance apparatus just installed in Japan. The disruptive discharge is oscillatory; that is, darts both ways from knob to knob, with terrific velocity and loud snapping noise—thunder.

But every oscillation sends out a wave, like a stone falling in water. If the two knobs be drawn apart, the lightning no longer has potential great enough to break down the air, so it expands into a brush of blue light electricity, like the bristles of a paint brush if widely separated.

Many flashing auroræ have been seen with every appearance of a brush discharge.



Cut 63. Curtain Aurora.

Cut 63 is the magnificent curtain aurora drawn by Dr. Hayes in the Arctic regions January 6, 1861. Thus: "The space within the arch was filled with black cloud, but its border brightened steadily, though the discharges were capricious; now glaring like vast conflagrations, now beaming like the glow of a summer morn. More and more intense grew the light, until from irregular bursts it matured into an almost uniform sheet of radiance. Toward the end of the display its character changed. Lurid fires

flung their awful portent across the sky, before which the stars seemed to recede and pale."

An account by the writer, written on April 17, and widely published in scientific journals:

GREAT AURORA APRIL 16, 1882.

"April 16, 1882, will pass into the history of astronomy as an eventful day. From morning to night the solar surface was in violent agitation. Colossal centers of cyclonic activity were watched in telescope during the entire day. There were 111 spots counted from 8 a. m. to sunset, the largest being 67,000 miles long and 48,000 wide. It was seen on April 15th, fifteen degrees on the eastern limb. Throughout the 15th it did not display unusual turbulence, but during the night activity set in, for on the next morning its internal structure had changed completely. It was cut into four portions by bridges which did not maintain their positions for an hour. They were widening, contracting and bending into ever-changing forms. They were much whiter and hotter than the solar disc. At 9 a. m. two tongues were seen pointing toward each other from opposite sides of the spot. At 12:30 p. m. the ends of the jets met and passed, leaving black space between. Shortly after they began a curvature toward each other, which, at 2 p. m., formed a circle, clearly a cyclone.

"At 9 p. m., while viewing Wells' comet in the telescope, it suddenly vanished. Looking out the dome to observe the cause, its obscuration was found to come from the rapidly rising arc of an aurora. The advancing apparition presented a yellowish-green arc of a circle, in altitude 18 degrees, half way to Polaris, and whose ends rested on the eastern and western horizons. The width of the arc was 55 degrees; clear sky revealing Cassiopeia, being below it, near the northeastern horizon. The center of the arc did not appear to be in line below Polaris, so its deviation was measured with the declination circle. The eastern end of

the arc was 15, and the western 25 degrees north of the equator, so the axis of the arc was inclined 10 degrees east of the axis of the earth. The streamers above the arc were parallel to the dipping needle.

"For nearly an hour the phenomenon developed no sign of coming grandeur, but at 10 p. m. three pillars of crimson light shot up to an altitude of 40 degrees from the western extremity of the arc, while a few yellow streamers ascended in the east. These outbursts seemed to be a preconcerted signal with the celestial pyrotechnists, for within two minutes the whole arc flashed and trembled, and then bodily expanded, ascending eight degrees. A halt was made, which lasted not more than a minute, when two flashes in rapid succession were sent throughout the widened arc, now 20 degrees broad. A mighty upheaval followed, the apex of the band at once lifted to Polaris, altitude 41 degrees, filling the northern heavens with supernal light bright enough to read by; but the terminals on the east or west did not draw nearer the equator, the energy being central. The great aurora reserved its forces a few moments, and then discharged, simultaneously, hundreds of columns of scarlet, violet and light yellow flames, instantly converging at the zenith. This display waned only to make way for another advance still more magnificent, and so on throughout the night, outburst succeeding outburst in rapid movement, until the rising sun put out all lesser glories.

"From midnight to 1 a. m. the action was at its height, the whole northern heavens, from horizon to equator being belted and banded with varying streamers, while flashes were incessant. A wave would appear on the north horizon and instantly rush to the zenith. Each impulse produced curvature in the straight columns, which at once became straight again until another disturbance rose up within a few seconds. The whole northern hemisphere quaked with the rapidity of lightning without cessa-

tion during the hour of maximum unrest, each upheaval hurled light directly to the zenith, with great velocity, whence it slowly drifted south, descending as far as Scorpio in the southern heavens, something unusual in northern auroras."

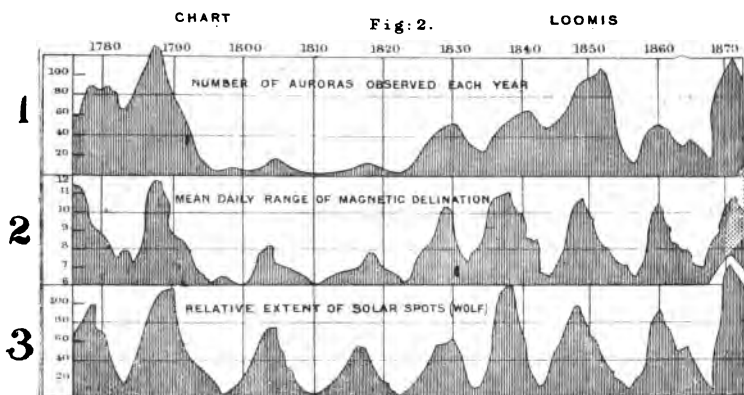
Professor S. P. Langley, of the Allegheny, Pa., Observatory, wrote on the 17th: "The auroral streamers converged to a point 10 degrees south of the zenith, while the fluctuating light seemed to pour upward incessantly like a pale flame. My object in writing is not so much to describe the aurora, however, as to call attention to the fact of its coincidence with a remarkable sun spot, which is now visible to the naked eye if defended by a smoked glass. We have had no such solar visitant for over ten years. It consists (at the time I write) of two large and five small nuclei, united by penumbrae, traversed by "bridges" of intense brightness. The area may be given in round numbers, at a minimum, as a thousand million square miles." The heights of aurorae are from 25 to 130 miles, and some are seen in America and not in Northern Europe, and vice versa.

Cut 64 is a most valuable record. It was made by Professor Loomis from a search of the records of the world. It shows the number of sun spots, auroras and magnetic storms for 100 years, from 1775 to 1875.

Figure 1 shows the number of auroras by the height of the vertical black lines. The ordinates (the numbers to the left), are numbers of auroras. Thus, in 1786, there were 117, and in 1810 only four.

Figure 2 is the average range of magnetic declination—that is, the number of degrees the needle moved every day. Thus in 1786 the average for the year was 12 degrees daily, the high column in figure 2 comes under the high number of auroras above it in figure 1.

In figure 3 is the number of groups of sun spots in 1786, about 110 groups, and it, too, is in line with the high columns of



Cut 64. Record of Sun Spots and Magnetic Storms.

auroras and storms among the magnets. The lines of abscissas are intervals of ten years. The coincidence is complete. In 1810 they were all reduced to a minimum. However, in 1805 there were quite a number of spots, but few auroras, while in 1870 they agreed again. Another spot maximum is due in 1903-4, and it is hoped the earth will have lively auroral and electro-magnetic times.

XXI.

THE SUN'S POTENTIAL.

"For consider Purna, that great vault of space, the sun shines forth and there is light, the clouds gather and there is darkness, the winds arise."—Kiounen Sutra, Chinese Scriptures.

"But if darkness, light and sight be separate and independent one of the other, then if you remove light and darkness, there is nothing left but void space."—Buddhistic Sutra.

"As one sun illumines the whole world, so does the one spirit illumine the whole of matter. O! Bharata."—Hindu Baagavad-Gita, Ch. XIII.

"When I see the sun and moon in eclipse, and the wise man in want, then I say Fate is master."—Hindu Hitopadesa, I, 44-6.

"Light, seeking light, doth light of light beguile."—"Love's Labor Lost," Act I, Sec. 1.

LIGHT POTENTIAL OF THE SUN.

Many measures have been made of the sun's light with several kinds of photometers. Its intensity has been a source of wonder to all who have ventured on the problem.

Light varies inversely as the square of the distance, and the sun is 93,000,000 miles from the earth; therefore, its intensity is inconceivably greater on the sun than here, yet will destroy the retina of the eye and far surpasses any light that man is able to make.

The light of the sun comes from the white-hot carbon envelope. But not only is a part absorbed by the gases above it, but its character is changed in color and activity. Professor S. P. Langley has shown that if the sun had no atmosphere, the surface would shine at least two or three times brighter than it does, and

with a blue-violet color, like the light of an electric arc, playing between carbon terminals. Most of these refined researches were made by Langley on Mount Whitney, California.

Absorption in the solar atmosphere can be seen by a college class at the same time as shown in cut 65.

This represents the eye end of a telescope whose object glass is pointed at the sun. The lenses of the eye-piece expand the light upon a card. Make two holes in the first card, one in the center

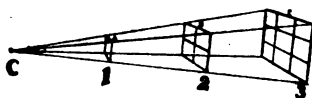


Cut 65. Image of Sun on Screen.

and one near the edge of the solar image, and receive the light on another screen. If the brightness of the spots is measured by a photometer (light measurer,) it will be found that the brilliancy of the circle near the edge of the sun is only two-fifths that in the center, having passed through a much greater depth of gases on the sun.

Now light and also heat or any other radiance varies inversely as the square of the distance is shown in cut 66, where the intensity of light from C, falling on the areas (1, 2 and 3), are equal. But the space in 2 is four times and in 3 nine times that

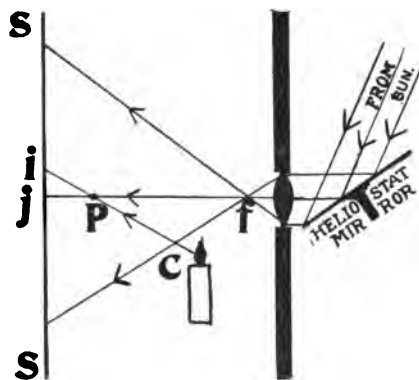
in 1, while the distances are 2 and 3, and 4 is the square of 2 and 9 of 3. The distance of the earth from the sun is equal to 1, and of Venus .72. The square of 1 is 1, and of .72 is .52; hence the quantity of light and heat received from the sun by Venus



Cut 66. Variation of Light With Distance.

equals 1 divided by .52, or 1.9, almost double that received by the earth. Human beings could not live on the equator of Venus.

Great skill has been employed in the measurement of radiance received on earth from the sun. This is done by comparison, as may be seen in cut 67, which is a meridian photometer in out-



Cut 67. Meridian Photometer in Outline. From Professor Young.

line, for the measures are made, when the sun is on the meridian, to secure the least depth of the earth's atmosphere, and, therefore, its minimum absorption. Light from the sun is reflected by the mirror of the heliostat through a lens into a dark room. Rays,

after passing the focus (F) of a convex lens, always diverge. Suppose the lens to be half an inch in diameter, it will form an image of the sun on the screen (S S). The size of this image depends on the distance of the screen from F. Suppose its distance is such that the circular image is 10 feet in diameter; that is, 240 times the diameter of the lens. Then the illumination of the disc on the screen will be $\frac{1}{57,600}$ th that of the sun, after allowing for absorption by mirror, lens and screen, for 240 squared is 57,600. Place a rod like a pencil on end at P and a standard candle at C. Move the candle back and forth until the shadow cast by the pencil at I equals in darkness that cast by it at J.

Hundreds of measures have been made on different days with varying clearness of the air, when it has been found that a standard candle must be placed at a distance of one meter from the screen to make the two shadows equal, one by the candle, the other by the sun. A standard candle adopted by physicists is made of sperm and burns 120 grains per hour, or 7.776 grams.

When the sun is on the meridian and allowance is made for absorption by air and glass, it illuminates a screen 70,000 times as strongly as the candle. The distance of the sun is 150,000 million meters. Square this, multiply the product by 70,000 and the result comes out 1,575,000,000,000,000,000,000,000 candle power. This is the quantity of light emitted by the sun, and is different from intensity, for an immense surface, even if not very brilliant, can radiate a large quantity of light, while the quantity of light emitted by any square unit as a square inch or centimeter determines the intrinsic brilliancy. Computing, it is found that the sun's carbon winding sheet is 190,000 times brighter than the candle flame (Young) and 150 times brighter than a calcium light, and from two to four times more brilliant than the electric arc light, all of which lights appear as dark spots when held between the eye and the sun.

XXII.

HEAT POTENTIAL OF THE SUN.

Whence are thy beams, O sun!
Thy everlasting light. —Ossian's "Poem to the Sun."

Sunshine, broken in the rill,
Though turn'd astray, is sunshine still.
—Moore's "Lalla Rookh" ("The Fire Worshippers").

Substance, and accident, and their operations,
All infused together in such wise
That what I speak of is one simple light.
—"Paradise, XXIII," Longfellow's Trans.

There is only one Deity, the great Soul.
He is called the Sun, for he is the soul of all beings.
—"Rig Veda."

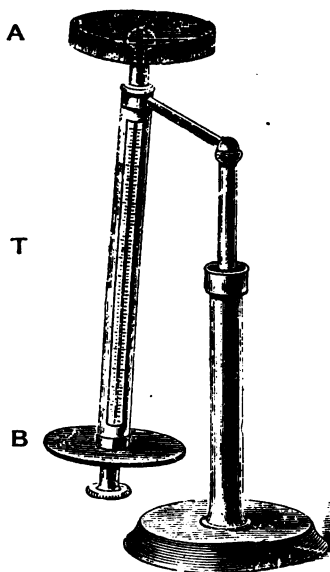
The glorious lamp of heaven, the radiant sun,
Is nature's eye. —Ovid's "Metamorphoses," line 165.

THE HEAT OF THE SUN.

Not less skill has been employed in measuring long heat waves than in short light undulations. Many eminent physicists have brought instruments of ever-increasing accuracy to the task. Some of these are complex and too technical to be explained here.

Perhaps the simplest and first of all, was Pouillet's pyro-heliometer (sun-heat measurer), as shown in cut 68, where A is a metal cylindric box one decimeter in diameter and of a thickness required to hold 100 grams of distilled water. The

upper surface is blackened with lampblack, for this is the best absorbing substance known, while the other parts are of polished silver, for this is the worst absorbing metal; the object being to secure all the radiance possible in the water box. The bulb of a sensitive thermometer is immersed in the water, the tube serving as an axis. The black surface of the box is placed at



Cut 68. Pouillet's Pyroheliometer.

an exact right angle to the sun, which is found when the shadow of the box coincides with the circular sheet of metal B. To use it, a screen is held between box and sun for five minutes. The water becomes of the same temperature as the air or sky, which temperature is read on the air scale at T. The screen is then removed and radiance allowed to fall on the black box for five

minutes, when screen is replaced and thermometer again read. The difference between these readings—the first and second five minutes—gives data for temperature raised in a cylinder of radiance one decimeter in diameter in 100 grams of water in five minutes. Were it not for allowances to be made for the small quantity of heat not absorbed by the lampblack and the amount absorbed by the earth's air the result would give the amount of heat that escaped the sun's atmosphere and fell on the earth.

Violle's actinometer and other forms are more accurate than Pouillet's, but after many thousands of determinations, by all these in all conditions of the air as to transparency, dust, water vapor, etc., the results agree fairly well.

THE SOLAR CONSTANT.

This is the result of a hundred years of research and is the constant or invariable quantity of heat that reaches the earth from the sun. Its quantity is beyond all concept. It surprised the early physicists and now fills with awe all who comprehend its mighty import. But really none can comprehend.

How much to allow for absorption in the atmosphere was found by taking a bolometer up to different mountain heights. This is one of the most remarkable instruments ever invented, and will be fully described just before the subject of radiance from the stars is taken up. By its use and subsequent mathematical computation by some of the ablest mathematicians, the following value has been obtained:

THREE CALORIES.

Thus, Professor S. P. Langley, after extended and accurate research on Mount Whitney, California, at an altitude of 14,500 feet, says:

"My conclusion is that we can adopt three calories as the most probable value of the solar constant."

Nearly as much hard work has been done to find this quantity as has been performed in finding the distance of the sun. This value is now adopted by the physicists of the world as the most accurate and comprehensive solution of the great problem.

A calorie is the quantity of heat required to raise the temperature of one gram of water one degree centigrade; that is, if the earth had no atmosphere, solar radiance would raise the temperature of one gram of water three degrees centigrade per minute for each normally exposed square centimeter of the earth's surface. The line A——B is one centimeter in length; a square whose sides are of this length would be a square centimeter, and a cube of the same width, length and height would be a cubic centimeter. If the cube were a little box it would hold just one gram of distilled water. And one degree centigrade equals 1.49 degrees of the ordinary Fahrenheit thermometer. Clearing of all metric values and reducing to ordinary English numbers, the quantity of solar radiance falling on every square yard of the surface of the earth at right angles to the central ray of the sun, if it could be converted into mechanical power in a perfect heat engine, would be what is technically known as slightly less than three horse-power. And this acts continuously—the stupendous flood of energy since the appearance of man on earth has not decreased, at least, within the period since the invention of stone writing, for delicate plants now grow and produce fruit and flowers in Egypt, Mesopotamia and India that are sculptured on the primeval walls and pillars of granite in the palaces of Memphis, Thebes, Nineveh, Ecbatana and Ellora, and whose fragrance and beauties were sung by our primitive and poetic ancestors round about the base of the Hindu Kuh, 800 miles east of the Caspian sea, B. C. 5,000 years.

The climate of the early Aryans has not changed—the solar heat has been constant since the Vedic poets sang. But from

that day until now, the time is merely equal to one swing of a pendulum in cosmic history.

The radiant energy falling on the deck of an ocean liner is sufficient, if it could be utilized, to propel the ship with greater speed than is now obtained from carbon. This radiation received is upon the theory that the earth had no air. The air cuts off fully one-third, and human genius so far is unable to use more than one-eighth of the remainder.



Cut 69. Solar Motor, at the Cawston Ostrich Farm, South Pasadena, California.

The mighty brain of Edison cannot hit upon a plan to make it more available. The heat engine built by Ericsson had 176 square feet, about 20 square yards of brilliant mirror surface reflecting the heat upon a boiler. The output of work was three horse-power, while about thirty-five horse power fell on the mirror.

Cut 69 is the great solar motor on the ostrich farm in South Pasadena. The circular mirror is a segment of a paraboloid

of revolution, 33 feet wide at the top and 16 at the bottom. The property of this conic is to reflect all parallel rays falling upon it to a focus. The boiler is a steel tube 13 feet long, in this hot focus. It holds 100 gallons of water and space of 6 cubic feet for steam. The interior of the conical surface is made of up 1788 mirrors, side by side. The whole apparatus is hung on an axis parallel to the axis of the earth, so it will follow the sun, like an equatorial telescope; and is also furnished with mechanism to raise and lower the mirror when the sun is north or south of the equator. The indicated output is eleven horse-power, with 210 pounds of steam, and it has pumped water at a maximum rate of 1,400 gallons per minute. Why not irrigate the waste places of the earth?

The mirror area is 70 square yards, and therefore receives 130-horse power of radiation, but uses eleven, or about one-twelfth. Since men appeared on the planet no such problem has presented itself as that of utilizing the eleven-twelfths now going to waste.

In the cut, A is the boiler, and E, the engine-house. The radiance of the sun should be caught on countless mirrors, and the energy transformed to work. A million accumulators ought to be stored with the potential form of electricity to move every wheel on earth and turn the darkness of night into the light of day.

XXIII.

DYNAMICS OF THE SUN.

"Horus: the strong bull. Friend of Justice. King of Upper and Lower Egypt. Lord of the periods of thirty years. Like his father Ptah-tanen. The son of the sun: Ramessu Meri-amun. The sun created him. To cause great rejoicing in the city of On, and to fill with riches the sanctuaries of his Creator. Lord of the two worlds: Ra-user-na; the chosen one of the sun: Ramessu Meri-amun, the son of the sun, who gives life of all stability and purity today as ever after."—Literal translation of left-hand face of the pyramidal apex of the Egyptian Obelisk now in Central Park, New York. Erected by King Thutmes III, B. C. 1500 in the Temple of the Sun, at On, Egypt.

"Thou sun of this great world
Both eye and soul."

—Milton's "Paradise Lost," book V, line 121.

VELOCITY POTENTIAL OF THE SUN.

The distance of the surface of the sun from its center is equal to one, and from the sun's center to the earth is equal to 214.5. The square of 1 equals 1, and the square of 214.5 equals 45,973.

All radiance proceeds in space as if emanating from a geometrical point. And 2 7-10 multiplied by 45,973 equals 124,127, therefore the potential of one square yard of the normal visible surface of the sun radiates 124,127 horse power all the time. Langley showed that very nearly three horse power per

square meter reaches the earth, and one square yard is less than a square meter, so that the incident energy would be close to 2 7-10 horse power. A "horse power" is that quantity of energy that can raise a stone weighing 33,000 pounds one foot high in one minute. This 124,973 horse power is the energy that gets through the solar vapors. How much leaves the actual carbon surface is not known. But this quantity, the residue, is beyond conception in any finite mind.

The union of hydrogen with oxygen develops the most intense heat known to be due to chemical activity.

SOURCE OF THE SUN'S HEAT.

The kinetic theory of matter—a vast science in itself—is now fully elaborated and chained subject to rigid mathematical law. The heat potential of any quantity of matter in any condition, whether in gas, liquid or solid, is known with precision.

The quantity in the sun is known, and its potential from a state of excessively rare gas down to its present size and density can be computed, and has been by many eminent mathematicians. It can be shown that if the sun were made of pure hydrogen, and should be ignited in an atmosphere of oxygen in sufficient quantity to unite with all the hydrogen, that the heat of this awful conflagration would not keep up radiation for more than 3,000 years. Geology shows that the sun has been pouring floods of heat, light and power upon the earth for inconceivable ages.

Whence comes the energy? It is clear that there is no "fire" on the sun. Fire is the union of other modes of matter with oxygen in general, yet other modes unite with evolution of heat. But on the sun modes are too hot to unify and form chemical compounds. At present it is not likely that chemism exists on the sun.

HEAT OF IMPACT ON THE SUN.

If a mass weighing 772 pounds be raised one foot and let fall and strike a rigid body, the precise amount of power required to raise it will be restored and will appear as heat, at the exact instant of striking. And as has been proven, the quantity of heat separated will be just enough to raise the temperature of one pound of water one degree F. But the heat appearing in the fall of 772 pounds one foot is equal to that separated by one pound falling 772 feet. This is Joule's equivalent. But a body falling 772 feet and making impact on the earth has a velocity at the instant of collision of 223 feet per second. This is the velocity potential of the mass of the earth and ranks high as an important element of knowledge in the possession of man. It can be at once applied to the universe by well-known mathematical equations.

Law: One pound of matter in motion with a velocity of 223 feet per second has stored within it sufficient kinetic energy to heat one pound of water 1 degree F.

Now throw this sounding line into the depths of the sidereal structure. With this magic number all space may be explored, and it can be at once computed what quantity of heat will be separated by the cessation of motion of any cosmical mass in space, soon as it is found how fast it is moving. Heat of impact varies as the square of the velocity of the colliding body. If any mass is seen in motion, to find the heat of impact:

Rule: Multiply the square of its velocity in feet per second by the reciprocal of the square of 223, which is .0002010899.

This number has tremendous analytical power, and there is no escape from its clutch for any mass, if it is moving.

If a mass fall from an infinite distance with unimpeded motion, that is, if it had been falling forever, it would take forever to fall through infinite distance, its final velocity at instant

of impact on the earth would be finite and would be 6.94034 miles, not quite 7 per second. Reduce this to feet, square the number, apply the rule, and the result is 27,855 degrees F., or the heat (maximum) that can be separated by any meteorite or comet that may hit the earth if it had no air.

The gravity potential on the sun's surface is 27,696 times stronger than it is on the earth's surface, and its velocity potential is 383 miles per second, from an infinite distance. Reduce this to feet, square the number, multiply the product by the above reciprocal, and the appalling result is 81,154,000 degrees F. liberated by impact of a falling body on the sun, if the sun's surface were rigid and it had no atmosphere. That is, if the body had been falling through an infinite distance in an infinite time. If these could obtain, the terminal velocity would be finite, 383 miles per second; yet might as well be infinite, so far as the limitations of the human mind are concerned.

Go into space. Twelve million millions miles, or half way to our nearest neighbor, and again apply the mathematical formula. It is found that the velocity with which a stone would strike the sun falling from an infinite distance, or from a small finite distance—twelve trillion miles—will differ by not more than one inch per second. So the gravity potency of the sun lies and acts almost entirely within its own immediate vicinity. The sun is not rigid and has a deep atmosphere. So a comet would not give up all its heat, on impact with the yielding carbon envelope.

All small comets would be dissipated into cosmic dust and debris as are all small comets—meteors—that enter the earth's atmosphere, by friction. And further, if the solar surface were as rigid as steel, it is known that a falling body could not hit the sun at right angles to a tangent, but would ricochet like a cannon ball on water, surrendering a part of its heat at each impact. Therefore the maximum 81,154,000 degrees of heat

could not obtain. This was written in 1882 to combat an alarmist who wrote that if the great comet of that year should strike the sun the earth would be consumed. The terrific heat of the sun is not all caused by a hail of cosmical matter on the sun, although no doubt a minute fraction is, not more than one per cent. For if more than this falls, the effect of the increased mass of the sun would soon be detected in the disturbances set up in the orbital motion of Mercury, Venus and the earth.

The quantity of matter in the earth is known, and from known laws of kinetics and thermo-dynamics it is shown that if a quantity of matter equal to the 1-100th of the mass of the earth should rain down in small chunks upon the sun with velocities of 383 miles per second, the heat of impact would keep up the radiation poured out by the sun for one year. The earth could apply the output for 100 years. But Mercury and Venus would be disturbed in their flights. Some other and mighty cause must be sought—one able to keep up the stupendous flow of heat.

XXIV.

SOLAR HEAT POTENTIAL.

"I have praised thy countenance, thou creator of the fullness of the earth, Lord of Abydos, who impartest light to thy servants, flashes of light to the darkness of night."—Egyptian Book of the Dead.

"Driving of Phœbus' chariot Phæton,
Struck by Jove's thunder,
Rests beneath this stone.
He could not rule his father's cars of fire."

—Ovid, Met.

"At this time Tathagata, from the character which was on his breast, caused to pour forth a precious flood of light, its effulgence like that of the Sun, its rays composed by a thousand colors, penetrating at once through the infinite worlds."—Buddha's Teachings to Ananda, Catena Chinese Scriptures.

"Mighty power was concentrated at the points of his hands, the son of the sun, Thutmes."—Glyphs on top of Obelisk, Central Park, New York.

HEAT AND GRAVITY.

If a stone weighing one pound on the surface of the earth be placed on the surface of the sun it will weigh 27.696—almost 28 pounds. At carbon "sea level" on the sun a barometer column, instead of being thirty inches as on earth, would be seventy feet high, if the atmosphere of the sun should be like that of the earth and of the same quantity. But the earth's air, if placed on the sun, would be flattened to a much thinner layer than now obtains round about the earth. The actual but to

men invisible surface of the sun must be subjected to enormous atmospheric pressure. Every square inch of the earth's surface is pressed fifteen pounds, and the same kind and quantity of air would press 420 pounds per square inch on the sun.

If the solar surface is liquid gas, and in all probability it is,—see Chapter XIV—then, from the dynamics of liquids it is known that pressure below the surface varies with the depth. At double depth there is double pressure. A place has been found on earth where the depth of the ocean is more than five miles. One cubic foot of water weighs $62\frac{1}{2}$ pounds, so on one square foot of this ocean floor the pressure is 2,000,000 pounds. One average cubic foot of the sun, if placed on the surface of the earth, would weigh 88 pounds, but on the sun it weighs 2460 pounds, for the mean density of the sun is 41 per cent greater than that of water, and gravity 28 times stronger. So $62\frac{1}{2} \times 1.41 \times 28$ equals 1,475 pounds. How inconceivable the pressure below the surface and near the center. The greater the pressure the more intense the heat so long as the sun is a gas, whether gas or liquid gas.

The thermal energy of matter is known with great accuracy, and the kinetic energy—that is energy of motion—of gaseous particles is also known with precision, and they are in the clutch of mathematical law, whence there is no escape.

Helmholtz first, and many mathematicians since, have many times computed the thermo-dynamics of the sun. All agree within the limits of minute details, that if the sun contracts in diameter nine inches per day, energy in the form of heat would be supplied at its present rate. The angular diameter of the sun is 1,924 seconds of an arc, and the linear diameter is 866,000 miles. So, one second equals 450 miles. But one second is about as small a dimension as can be seen by a good eye in a large telescope. With a contraction of nine (9) inches per day,

it would require 9,400 years to contract one second, an amount so small that it could be detected only by a micrometer.

In Chapter XXIII, it was shown that if a body is moving with a speed of 223 feet per second, and if all its motion instantly comes to an end by its striking a body rigid enough to flatten out the moving body into a very thin layer of particles all at once, and if the falling body weighs one pound, the heat liberated will be enough to raise the temperature of one pound of water one degree F. Now it makes no difference whether it falls rapidly or slowly, the quantity of heat surrendered by friction against adjacent particles will be the same. Hence, the heat of the sun is caused mainly by friction, and cessation of motion of particles hitting against each other in the process of contraction.

This doctrine is now adopted by all the mathematical physicists of the world. The diameter of the sun was once full thirty million times greater than it is now—that is when expanded, in all directions to a distance equal to half that of the sun's nearest neighbor. Its radiant energy was then all potential. Each particle on the periphery of the primordial gaseous sphere has been a falling body since, and computation is able to determine the kinetic energy of the entire mass. For the mass is also known.

When the diameter of the sun was twenty-five trillion miles its temperature was that of absolute zero—461 degrees F. Contraction due to central gravity set in and has continued until the present and is now in active operation. After inconceivable ages, long heat waves began to undulate and after the lapse of more millions of years short light waves appeared. The foundation of the mathematics of solar potential was laid by the brain of Helmholtz, but his formulas have been much elaborated since his death, notably by Professors See and Doolittle, with astonishing results. Thus, while the gaseous cosmic sphere contracted from its original diameter of twenty-five trillion miles down to

the insignificant diameter of seventy-two million miles, when it just filled the present orbit of Mercury, it radiated only one eighty-third of the energy it has since emitted. This vast problem, all based on rigid mathematics, throws much light on the past career of man on earth, upon the glacial epochs and other geological problems. And these relate to the future of men upon the earth.

TOTAL ENERGY OF THE SUN.

XXV.

And sitteth awhile on Greyfel
 On the marvelous thing to gaze, ..
 For lo! the side of Hindfell enwrapped
 By the fervent blaze,
 And naught 'twixt earth and heaven
 Save a world of flickering flame,
 And a hurrying, shifting tangle,
 Where the dark rents went and came

—Saga of the Volsungs.

He opened the great gates in the darkness shrouded;
 The fastenings were strong on the left and right.
 In its mass he made a boiling.

* * * the night be overshadowed

* * * until the shining of the day.

His [the sun's] horns are breaking through to shine on the heavens.
 On the seventh day a circle he begins to swell,
 And stretches toward the dawn further, when the * * *

—Fifth tablet of Creation Myth, primitive Babylonian script.

HISTORY OF THE SUN.

When our sun had a diameter of twenty-five million million miles, which it had when extended halfway to its nearest neighboring sun, a volume of it, of the size of the earth, contained a quantity of ultra-gaseous matter which, if condensed into one chunk, and brought to the earth's surface and weighed, would weigh 127 pounds. The volume of the earth is 260 billion cubic miles, so it required 292,000 cubic miles to contain matter

weighing one grain. A piece of brass of the size of this square, one-fortieth of an inch thick, weighs one grain. This is easily computed for the sun, planets and moons in the solar system contain a mass of two octillion tons, nearly. 

The primordial solar nebula must have been at the absolute zero—461 degrees F., for two of the particles must either hit together to separate heat by friction, or they must unite chemically. But they could do neither when long distances apart, for every one must gravitate toward the center of gravity of the whole mass. Since a cubic space inclosing 292,000 solid miles would be 66 miles on each side, the little sheet of brass, if cut into 292,000 portions and equally distributed, would be one mile apart. Nothing but the Thomsonian corpuscles, the 1-1000th of the mass of the unit hydrogen particle, could occupy the space. And they were not very closely packed. The mass began contraction at an exceedingly slow rate, for gravity is weak at a distance of $12\frac{1}{2}$ trillion miles. All the heat radiated from that time has been caused, so far as science can now see, by collisions of the particles. For chemical union cannot take place in terrific cold or heat. Chemism is completely arrested by the cold of liquid air, and this is hotter than the absolute zero. If at any time the temperature of the subsiding cosmical sphere was such that two or more phases could change their rates and unite into a compound, all such combines have long since been broken up by the immensely greater heat of friction now resident in the sun. For no spectroscopist believes that compounds now exist in the solar globe. It is far too hot for the presence of either "fire" or chemism.

The original gaseous sphere kept on shrinking, each particle moving on straight lines, and gradually nearing each other. Let this process continue for unnumbered eons, until finally the whole had subsided to the present orbit of Neptune. Its diameter then would be 5,580,000,000 miles. Again computing its density,

it is still found to be 16,695,000 times less dense than the exceedingly rare gas, hydrogen.

All students of chemistry know how attenuated is the elusive hydrogen, and with what care it must be kept from escaping, for air is 14.44 times more dense. Platinum just begins to emit light when its temperature is 525 degrees C., and the carbon filament in an incandescent lamp bulb at 390 degrees, iron at 378 and gold at 417 C. Therefore, when the sun's periphery reached Neptune's distance, it was yet enshrouded in primeval darkness and invisible from space. And it is doubtful if its temperature was much, if any, above the absolute zero.

From expansion of Helmholtz' original formulas of solar heat potential from primordial gas to solid, Dr. See has computed the entire quantity evolved by the impact of all the particles in two octillion tons of matter and finds it to be 49,048,200 degrees F. This is the heat separated by contraction from either an infinite diameter, or from a diameter of only 25 trillion miles. In Chapter XXI it was shown that the terminal velocities of collision on the sun of a stone that started to fall at an infinite distance, or from a distance of $12\frac{1}{2}$ trillion miles would differ only by a fraction of an inch per second. And in these researches into heat potential it is now found that if the original gaseous mass began to contract from an infinite diameter, or from a finite diameter of say 25 trillion miles, that the difference of the heat output is small; so velocity potentials and the potential of heat agree in these elaborate analytical investigations. Coming down to the Neptunian orbit and again applying the formulas, it is found that if the primitive gaseous mass began to contract even at that small diameter, the quantity of heat liberated would be 49,040,750 degrees F., only 7,250 degrees less than if it had subsided from an infinite diameter, or a finite of 25 trillion miles.

XXVI.

THE ANCIENT SUN.

"So, I wot, was earth melted in the glare of burning fire. Then, troubled in spirit, he hurled him into wide Tartarus."—From Hesiod Theogony.

The mysteries of catalysis are being exploited in the effect it has in relation to life. This is the action of a mode of matter on other modes causing them to unite without being itself affected. Finely divided platinum is a catalytic agent, and so is a sheet of platinum if absolutely clean. Thus: alcohol dropped upon powdered platinum becomes changed to acetic acid, the platinum suffers no change whatever, except becoming heated. If formic acid comes in contact with fine platinum particles, it is changed to carbonic acid. If platinum foil is put into a mechanical mixture of oxygen and hydrogen, a chemical union begins, resulting in the formation of water. The platinum becomes hot; after the process is complete it cools, and no change is noted. The metal can repeat the work indefinitely, with no apparent exertion or energy—and the mystery is where the energy comes from. All this has been known for years to chemists. But now comes the bio-chemist Loeb of Chicago and applies this remarkable action to the production of the first life on the inorganic earth. Thus life might have been caused by the mere presence of a third mode of matter. These promoting agents are

called enzymes (ferments). Modes besides platinum act as enzymes, gold, silver and others will thus act. Thus the enzyme, called oxydane, in the lungs enables oxygen of the air to be assimilated and sustain life, while many other enzymic agents are found in the living body. He has apparently shown that all life is due to the action of the enzymes. (See Loeb's Columbia College, N. Y., lecture.) But this action has all along been supposed in these notes. Since enzymes suffer no change, and as the sum of energy in existence is constant, these bodies merely direct radiance already saturating space, constantly poured forth from countless suns. For actinium and polonium perpetually direct waves against and through other bodies, being themselves without change.

In all researches into the physics and chemism of the primitive gaseous sphere, catalysis has not been introduced. This is one of the most mysterious activities in nature. It is action by influence. Professor Charles E. Munroe (Proc. Am. Ass'n, Cleveland, p. 119) "finds in the behavior of compound radicals, and in the change wrought by the factors of time, mass and temperature, positive evidence of the effect of environment and qualifying conditions in determining the production of species."

That is, chemical union is in many cases determined by what is adjacent. Applying this to the dwindling sun it is seen that particles might approach the center side by side for ages and not unite until a third particle was encountered which by its mere presence causes them to unify without itself suffering any change, for it is still able to cause others to unite on its long flight to the condensing central sun.

Heat appears when differing phases of matter have their rates changed by uniting, or before, so they will unite; and if the activity is intense enough, light radiates; but in the archaic mass neither was liberated for untold ages of subsidence, vast periods of weak catalytic action, and eons of rarely oc-

curring collisions. Affinity, heat and light are late products of the sun.

This theory that catalysis was the first mode of energy that began to work on the primordial mass is offered for what it is worth, if anything. For later, affinity laid hold on matter, and wrought; but this is not catalytic.

Electro-chemism and polarity, so ably treated by Berzelius, Faraday and Ampere, most fascinating subjects, must be omitted. As soon as two corpuscles united by the mere influence of a catalyst they became centers of increased activity, but they all fell toward the forming sun in the center.

After great subsidence, through vast periods of time, the sun became smaller, with liberations due to increased collisions, of heat and then light, succeeded or preceded by electricity, electromagnetism and polarization.

All phases of energy appear now in the still condensing sun. The monads of Liebnitz, pantogen of Hinrichs, protyle of Crooke's, vortex rings of Kelvin, atoms of Aristotle and Lucretius and every other concept, ancient or modern, are comprehended and included in Thomson's corpuscles and Crooke's electrons—"bodies smaller than atoms." These fill every requirement made by physicists and mathematicians of all ages in striving to account for the successive evolutions through which all matter must pass.

Catalytic force is "that substances by their mere presence, and not by their affinity, have the power to rouse latent affinities, so that compound substances undergo reaction and a greater electro-chemical neutralization occurs."—Berzelius.

"A catalyst is any substance which alters the velocity of a chemical reaction without appearing in the final product." "There seems to be no kind of chemical reaction which cannot be catalytically influenced, and no chemical substances, whether elements or compounds, which cannot act catalytically."

"The presence of hydrogen ions accelerates most chemical re-

actions, so they must be regarded as catalysts of great generality; and there are especially among the enzymes, specific catalysts which only exert their accelerating action on perfectly definite substances."

"We have three different means of influencing the velocity of chemical reactions: temperature, concentration and catalysis."

"Oxidation of naphthalam by means of sulphuric acid with speed, can only be brought about in the presence of mercury."

"A trace of gas may cause the liberation of an entirely disproportionate amount of another gas."

There are four phases of catalytic activity known: First, release in supersaturated systems; second, catalysis in homogeneous mixtures; third, catalysis in heterogeneous mixtures; fourth, enzyme action. (Professor Oswald, "Nature," April 3, 1902.)

If the hypothesis of primeval catalytic action is accepted, then a host of difficulties that have so long troubled physicists and chemists in accounting for the successive steps in the evolution of the sun will vanish. For corpuscles are known to be surrounded by a field, for a long time called "sphere" of action. Thus heat and light are recent; the sun has been invisible until lately. But electricity may not be merely a late worker, for indeed it may be the primordial catalyst.

XXVII.

THE RADIANT SUN.

"After having produced the universe, He, whose power is incomprehensible, vanished, again absorbed in the supreme soul."—Laws of Manu, Bk. L, Shloka 50, Archaic Hindu Phil.

Professor Langley has shown that of the total amount of radiation from the sun, 19 per cent is in the visible portion of the spectrum. There is but one kind of energy radiated from the sun—the light, heat and chemical effects depend entirely upon the state or condition of the matter upon which the differing wave lengths may happen to fall. Here is a quotation from one of the most eminent physicists which the world has ever seen:

"Up to 1872 it was almost universally believed that there were three different kinds of entities, actinic, luminous and thermal, represented in the spectrum. There is one radiant energy which appears to us as 'actinic,' or 'luminous,' or 'thermal' radiation, according to the way we observe it. Heat and light, then, are not things in themselves, but different sensations in our own bodies, or different effects in other bodies, are merely effects of this mysterious thing we call radiant energy."—S. P. Langley, Proc. American Association Science, Cleveland session.

The Italian physicist Melloni says: "Light is merely a series of calorific indications sensible to the organs of sight, or vice versa, the radiations of obscure heat are veritable invisible radiations of light."

Melloni wrote this nearly sixty years ago, in 1843, but it was not adopted until Langley by his elaborate researches, more refined and complex than all preceding, proved it. The doctrine of one radiant energy is now adopted by the great physicists of the world. It only remains now for them to say there is only one matter.

From Helmholtz' formulas it has been shown that if the sun, whose mass is two octillion tons, contracted from an infinite diameter to a diameter down to the present diameter of the orbit of Neptune, the total heat separated by friction and collisions of its particles, was sufficient to raise the temperature of two octillion tons of water 7,202 degrees F. When it collapsed to the present distance of Jupiter—diameter one billion miles—the heat liberated would heat two octillion tons of water 43,960 degrees F. and that contracting from an infinite diameter or from a finite diameter of twenty-five trillion miles down to its present diameter 866,000 miles, the heat sent into space has been sufficient to heat two octillion tons of water to a temperature of 49,050,000 degrees F. For it is known just how much work would be done, if one carried a ton of matter away from the sun to twelve and one-half trillion miles, or to any distance even to infinity.

To the non-mathematical reader it is well to state that when a formula is applied, at varying distances, rates, pressures, etc., they often run out toward the infinitely small or infinitely large. Since the law of variation of the formula in question is known, it is also known with unerring accuracy when the formula will come to an end.

And the work done in carrying a mass away from the sun—that is, work of lifting the mass—as a stone is lifted on the earth—is equal to the work of drawing it in from space. Thus the gravity potential at any distance from the sun is easily computed, and from thermodynamic laws, the heat equivalent of work

is known. The heat equations have been solved on the hypothesis that the sun in the long period of its subsidence was homogeneous throughout—and the vast quantities of heat seem large enough. But Anne Sewell Young of the University of Chicago made computation with the formulas of Helmholtz on the theory that the sun was all the time more dense in the center and therefore the entire mass was not homogeneous. And she proved that if it were denser in the central portions, the heat would be greater! But the mighty power of the sun is exerted in space near it. For if the sun contracted from a diameter of twenty-five trillion miles, or began to contract at a diameter equal to that of the earth's orbit, or 186,000,000 miles, the heat output would have been 48,819,600 degrees F., which, subtracted from 49,050,000 degrees, equals 231,000 degrees, or only 1-215th part, was radiated from the beginning of contraction until it dwindled down to the insignificant diameter of the orbit of the earth. Therefore, when the periphery of the shrinking sun was passing the earth's orbit, it was beyond a doubt invisible from space, from any light due to rapid rates caused by heat. Computing again at the orbit of Mercury, 1-83d of the heat was poured into space since it began to contract. Make the sun twice its present diameter and again apply the formula, and the result is that in subsiding to that small diameter, it lost only half its heat. The best estimates of physicists are that the sun is radiating heat enough to reduce its temperature $2\frac{1}{4}$ degrees per year, and 49,050,000 divided by this gives 21,800,000 years as the life of the sun. Helmholtz made it 22,000,000 years. Newcomb says not much above 20,000,000, but no mathematician computes more than 22,000,000 years. It is considered that it has been radiating heat 18,000,000 years and has 4,000,000 yet to run its mighty furnace.

All these deductions are made on the assumption that all the heat has been caused by contraction. But chemism must have

XXVIII.

THE SPECTRO-BOLOMETER.

"How impossible to exhibit in words the infinite portions of the mysterious universe! Each single atom evolved from all the atoms, each atom evolved from the aggregate of all. Revolving thus unhindered they unite in one harmonious whole."—Liturgy of Kwan-Yin, Buddhistic, Chinese service.

A threefold measure dwells in space—
 Restless length, with flying race;
 Stretching forward, never endeth,
 Ever widening, breadth extendeth
 Ever groundless, depth descendeth.

—Schiller in Sentences of Confucius.

Shine out, fair sun till I have bought a glass,
 That I may see my shadow as I pass.

—"Richard III," act 1, scene 2.

LANGLEY'S BOLOMETRIC SPECTRUM.

Before entering upon a study of the stars it is necessary to completely understand the elaborate researches of Professor S. P. Langley in hitherto unknown radiations at each end of the visible spectrum. He discovered waves far beyond the red and violet, and surpassed all other previous physicists in the delicacy of his determinations. So far in this series less than one octave of vibrations has been treated. For if a tuning fork beats

256 times per second and another 512, the sound will be raised one octave in pitch, because 512 is twice 256. The longest wave of light in the extreme red vibrates 395 trillion times per second, and the shortest violet 764 trillion. This is not an octave, for twice 395 equals 790. Therefore any rate greater or less will not appear as light, and the visible part of the sun's radiance is only a small fraction of the output.

If a metal wire is carrying a current of electricity and the wire be heated by any external means, the resistance is increased and less electricity flows, and if cooled the resistance is diminished and more current passes. This is an important law in electrical conductivity, and is the principle upon which the bolometer is made. Thus it is now believed that if a wire of absolutely pure metal could be cooled to the absolute zero, it would offer no resistance to electricity. The essential part of a bolometer is the excessively thin platinum thread or filament, called the nerve of the instrument. It is hundreds of times more sensitive to heat than any nerve in the human body. Here are the details of Professor Langley's most perfect instrument:

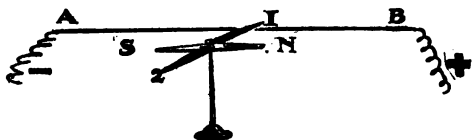
Length of platinum fiber, $\frac{1}{4}$ inch; width of platinum fiber, 1-500th inch; thickness of platinum fiber, 1-25,000th inch.

When this is moved along in the spectrum beyond the red it detects waves invisible in any apparatus, and also detects cold regions—that is, vacant spaces corresponding to the black Fraunhofer lines in the visible spectrum. Thus cold—i. e., absence of heat waves—is comparable to darkness, absence of light waves.

This could not be done were it not for the law of variation of the current by heat. The records and maps of the infra red region are made by a most delicate galvanometer, which must now be explained.

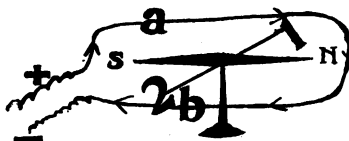
Law XVIII, chapter XVIII—A magnet free to move will make an angle with a current of electricity.

Cut 70 represents a magnetic needle N S balanced on the sharp point of the upright, and A B is a wire. Send electricity through the wire and the needle will swing from the direction N S to the new direction 1 2, making an angle with the wire, and the size of the angle depends on the strength of the current.



Cut 70. Deflection of a Magnet by a Current of Electricity.

But the long heat waves beyond the red make weak currents, not able to deflect the magnet enough for the angle to be measured accurately. So currents are strengthened, increasing the number of turns of wire by rolling into a coil.



Cut 71. Suspended Needle With Increased Deflection.

This is made clear in cut 71, where a b is one turn of wire round the needle. Several hundred turns, side by side, would constitute a coil of great multiplying power. That is, parts of wire both above and below the needle act. The current in the upper wire a, is aided by that in wire b, and makes a stronger electromagnetic field within the space inclosed by the wire.

In cut 72 is shown the turns of the wire in two coils. Above them is a thin disc ruled to degrees and minutes, and above that

the needle, exactly above another, whose end is seen within the field of the coils. They are connected so the upper turns precisely as the lower, and both are suspended by a fiber of silk, and the whole delicate apparatus is kept under a glass to protect it from currents of air. When a current of electricity passes through the coils, the needle turns and the strength can be determined by

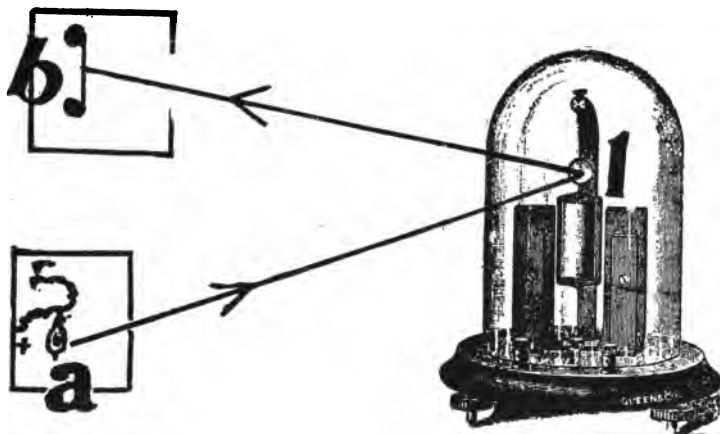


Cut 72. Galvanometer. The Coil of Wire is Under the Plate and Needle.

reading the scale. It is very sensitive and has been used since Oersted discovered its law in 1819. But so refined were Langley's researches that it could not be used, for far beyond the red, the heat was not strong enough to vary the resistance of the platinum nerve sufficient to vary the needle.

So a new form of galvanometer was devised, whose every principle is shown in cut 73, a d'Arsonval, not having a diagram of Langley's. This has no needle, its place being taken by an extremely small mirror at 1. Its field is supplied by the poles of a U permanent magnet and a rectangular coil inclosing a cylinder of

thin iron is suspended between. The coil acts as does a needle when the current is passed and turns and the mirror with it. In a dark chamber, *a*, is a minute incandescent lamp, whose light falls on the mirror. In a box, *b*, the light strikes a long sensitive film, like a biograph film, which is rolled from one spool to another, as shown, by a clock which does not appear. The film can be placed as far as required, so that if the mirror rotates only the 1-1000th of an inch, its reflected ray may be made to trace an entire inch on the film—and thus a minute motion invisible to

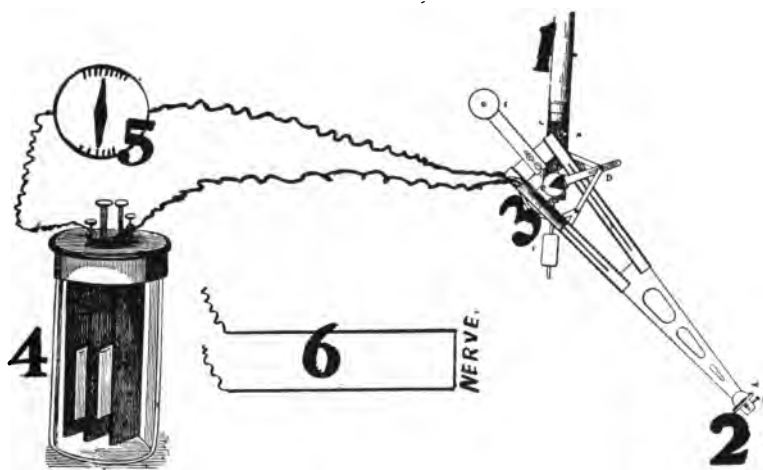


Cut 73. Mirror Galvanometer With Graphic Recording Apparatus.

the eye is made visible and recorded when the graph is developed. The result is that when the bolometer nerve is struck by a heat wave in the spectrum, the mirror moves and makes a record on the film. And when a cold place is passed by the nerve the clock draws the film along, so that the tiny point of light is deflected the other way, thus one-one hundred millionth of a degree is measured. When the sensitive galvanometer was made, it had to be put in a room inside of another room to avoid changes in tem-

perature, and the temperature was kept constant automatically by heating and cooling coils, so that the variation was only one-tenth of a degree.

And when it was tried to explore farther and farther into the long weak heat wave region, it was soon found that glass prisms absorbed the faint heat, so prisms made of rock-salt were used, for this substance allows more heat to pass than any other known.



Cut 74. Langley's Spectro-Bolometer.

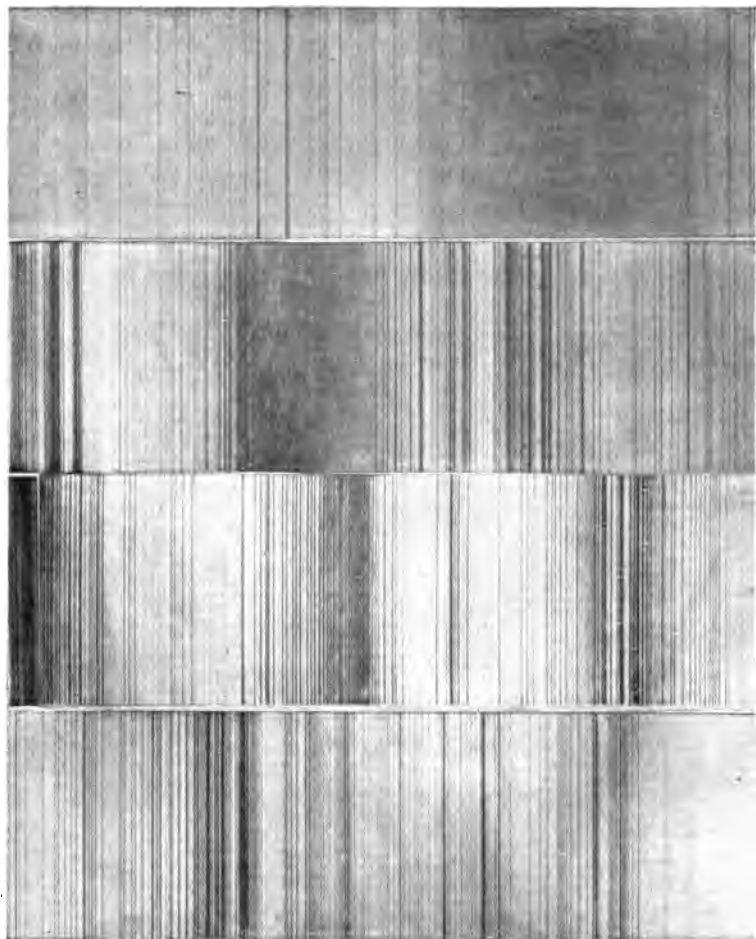
The reader will understand that the reason why the mirror moves is the variation in the strength of the current of electricity flowing in the coil between the poles of the upright magnet in cut 73, and the variations in the strength of the current are caused by increased or decreased resistance in the platinum nerve caused by heat and cold spaces in the infra-red spectrum of the sun.

Not having a cut of Langley's latest bolometer, cut 74 is sent, of a bolometer with which he made many discoveries.

Fig. 1 is collimator of spectroscope. The rock salt prism is shown to the right of 3. Radiance from the sun comes through the tube 1, passes through the prism of 60 degrees angle, which disperses the heat waves into a long invisible spectrum beyond the red. It falls upon the reflector 2, and is reflected into the end of the bolometer, 3, and falls on the little platinum fiber, which crosses it within. The mirror, 2, is turned so the thermal spectrum passes in review from end to end, and every portion is examined. Fig. 4 is a battery and 5, the outline of the galvanometer. Fig. 6 is an outline of what is inside the tube 3, showing the nerve and wires that connect to battery. It is placed in tube to protect fiber from any heat but that from the spectrum.

Professor Langley's new bolometer, with which he made his latest researches, is the most sensitive instrument ever constructed. Its achievements have crowned with success twenty years of the most arduous labor, where human skill is taxed to its utmost.

Cut 75 is that of the long infra-red or new spectrum just published—Smithsonian Report 1900—by the now world-honored Professor S. P. Langley. It is thirteen times longer than the spectrum which makes impress on the eye. The wide dark bands are mysterious. Their cause is unknown—that is, what modes of matter absorbed them—for of course absorption is the real cause of all dark and cold spaces in the solar spectrum. And now all the spectroscopists of the world will make experiment on metals to find which absorbs, so as to produce the bands. Vast additions to the sum of knowledge has been made by Langley in these long-continued and refined researches. The ultra-violet region, to the left of the visible spectrum is not shown in cut 75. For if it were: "It would take nearly a hundred feet of map to depict it on the prismatic scale, though this is caused by but a small fraction of the sun's energy, so monstrous is the exaggeration due to the dispersion of the prism. It really contains much less than the one-hundredth part of the total solar energy



Cut 75. Professor Langley's Infra Red, or Thermal Spectrum. The Strips Should be Placed End to End.

which exists, the visible spectrum containing perhaps one-fifth the energy of the sun."—Langley, p. 684, Smithsonian Report, 1900. Thus the length of the spectrum beyond the violet is still unknown—depending entirely on the most sensitive graphic plates. For the waves out there cannot be detected by any other means than by graphs, or their fluorescing properties. Their lengths are known to be exceedingly short, and it is highly probable that they continue to become shorter until they become electro-magnetic Roentgen waves. A new world to be explored is opened here for all discoveries are "pointing the way to future knowledge of the connection of terrestrial life with that physical creator of all life, the sun."—Langley, p. 683. Thus calling the length of the light spectrum 1, that of the heat spectrum is 13, and of the chemical, at present unknown. So that now the spectrum known to Newton, Brewster, Wollaston, Kirchhoff, Fraunhofer, Bunsen, and all early students, scarcely bears resemblance to the wonderful map just given to an expectant world by that tireless worker, Langley.

The problem of all ages is now to either lengthen them for use of man or find some way to cut them out of space and make use of them as they are.



Cut 76. Langley's Bolograph. The Visible Spectrum From V to R is That Known Before Langley.

The energy of the sun is irregular in its distribution. The thermal waves have varying intensities out to the extreme limit. The lines and bands detected by the bolometer nerve vary as much in width as the dark lines in the light spectrum. For cold in the bolometer spectrum corresponds to darkness in the visible. It is difficult to secure a bolograph; that is, to get an im-

pression on plates of the thermal region. These long, slow waves are not suitable for graphic work. Indeed, the waves perpetually issuing from radium are more powerful and print a stronger graph on the same sensitive plate.

LANGLEY'S LATE DETERMINATION OF ENERGY IN THE SPECTRUM.

Ultra violet region contains.....	1-100th
Visible	19-100ths
Thermal beyond the red.....	80-100ths
Total equals	1

But the visible contains much heat, so the energy called light is exceedingly small.

PART III.

XXIX.

THE STARS.

I look down through that oval ring of stars,
And see the far off earth, a trembling speck,
Dust-mote, whirled up from the chariot wheels of the sun,
And pity their small hearts that hold a man.

—Sill's Semele.

And the ray-crowned Balder said,
Far to the south, beyond the blue there spreads
Another heaven, the boundless,
No man yet hath reached it.

Matthew Arnold, Balder Dead.

THE STARS.

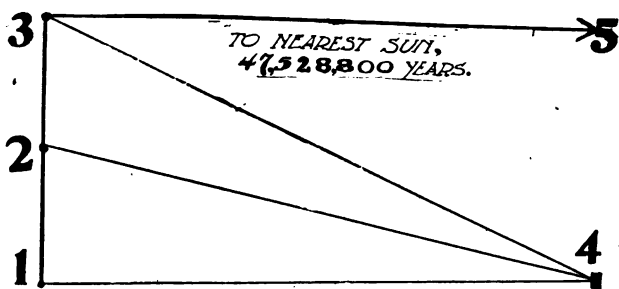
The word stars should not be used in scientific literature; it has no meaning. All stars are colossal suns at terrific heats.

All celestial objects ever seen by the unaided eye of man since his appearance on the earth, except the moon, Mercury, Venus, Mars, Jupiter, Saturn, comets and meteors, are suns. And that marvel of all ages—the spectroscope—proves them all to be similar to our own sun, in composition and temperature. Stellar astronomy is a new science, and its more refined departments are scarcely more than ten years old. It is now being studied with feverish intensity, and the hours of night are not long enough. Costly spectro-photographic apparatus and elaborate measuring instruments are being installed in all the great observatories; me-

chanism that can weigh a hair 1-4 inch in length, measure the diameter of a spider's web, detect the 1-10,000,000 degree of heat and measure the 1-250,000,000 of an inch in terms of lengths of waves of light.

When the astronomers of the seventeenth century began to realize the actual distance of even the nearest star, the mere thought of it was simply stupefying, crushing and depressing to the spirit of man. An awful feeling of insignificance came stealing over the minds of the early astronomers, and they merely had a glimpse of the incredible wastes of space now known.

The nearest neighbor the sun—our sun—has, is distant 25 million million miles (25,000,000,000,000 miles). Or, in short, 25 trillion miles.



Cut 77. Diagram Showing Distance of the Sun's Nearest Neighbor.

In cut 77 a futile effort is made to convey some impression of this stupendous distance.

Let the straight line 1, 3, be a railway, and 1, 2 and 3 stations, while 4 is a distant house at right angles to an observer at a car window, when the train is at 1. Let it move to 2, and the observer may see the house, by moving the eyes, only, but on arrival at 3, not only the eyes, but the head must be turned. Let 1 be the earth today, 2, the sun, and 3, the place of the earth in

six months; the distance from 1 to 2, being 93,000,000 miles. When at 1, let a person get the eyes centered on the nearest star in direction 1, 4. Then so the observer shall not move his eyes to the distance of the 1-100,000th of an inch for six months, let him be instantly turned to stone, and at the end of the half year be as suddenly restored to life, and open the stony eyes, when lo! the star is in the center of the eye still—that is, the displacement of the earth 186,000,000 miles has no effect that can be detected by the eye, for it sees the distant star in direction 3, 5, exactly as from 1 to 4, the cardinal fact standing out that the lines 1, 4 and 3, 5 are parallel.

ASTRONOMERS' EARLY STRUGGLES.

If at 3, his train should turn and go on a straight line to the nearest star, incessantly with a speed of one mile per minute, it would require a time of 47,528,800 years to traverse the mighty void.

In 1530 Copernicus taught that the earth moved around the sun, and not the sun about the earth, as had been held since the end of Egyptian astronomy. Soon as he expounded the doctrine, astronomers and mathematicians, the few that then lived, accepted it. At once, the combined power of Europe was raised as a barrier against them. For the unanswerable argument was raised that if the earth moved from one side of a vast orbit to the other, the stars must be displaced in the opposite direction like the house in cut 77. And how intense was the longing of astronomers to prove the Copernican truths. They had no telescopes, and of course could not detect any shifting among the stars.

Then came Galileo in 1609 with his miniature telescope. In time this was much improved and astronomers said, surely now we can detect lateral displacement in the stellar hosts. And so they toiled on year after year, with absolutely no result. Even the telescope that magnified 1500 diameters failed utterly to show

that the lines were not absolutely parallel. And enemies increased. Astronomers themselves were dumb, and one of their number, as brilliant as any, Tycho, in despair, gave up the Copernican theory, which his mathematical brain could not accept on account of the to him totally impossible magnitude of the universe. Soon after, quite a number of able astronomers appeared, but none could detect any angle or want of parallelism between lines drawn to a star from opposites sides of the earth's seemingly mighty orbit.

BAFFLED.

During the career of man on the earth no such complete barrier to his intellectual advance had been encountered. His restless mind was confronted with a problem—to tell the distance of a star—before which he now found himself as a child on the shores of an unknown sea. And man felt himself humiliated and disconcerted. For perhaps one reason why Tycho Brahe opposed the true theory of Copernicus was the unutterable consequences sure to follow if it really were true, and this outweighed his judgment. For let one cubic inch contain one million particles of dust—then in an ordinary room each particle is as large or larger in proportion to the cubical space in the room—than the earth is to space shown in modern telescopes.

Thus from 1530 to 1650, or 120 years, the astronomers of the world were simply overwhelmed with the awful majesty of the sidereal structure. The more they studied the more the mighty concept grew and the more absolutely insignificant did the earth and man become. And the problem of measuring the distance of a star seemed past human solution.

THE MICROMETER.

About 1650 this marvelous engine for the conquest of the universe was invented. Hope revived, all was animation in the astronomical world, incredible labors rivaling the works of Hercules were commenced, observatories were erected, men

toiled as only men will if they are on a sinking ship. Mathematics expanded, the lethargy of the dark ages was aroused into a scene of activity, which even now is increasing in momentum in geometrical progression.

Of such extreme value is the micrometer, and so far reaching, epoch making and important in the evolution of intelligence, that all should study the wondrous instrument. Cut 78 is the filar micrometer in the Lowe Observatory.



Cut 78. Filar Micrometer in the Lowe Observatory.

Figure 17, cut 78, is the tube which has a screw thread at the bottom, to adjust to the telescope. Just below the eye-piece, 21, are two spider webs crossing, and when pointing to the zenith, the eye-piece, 21, would be toward the floor.

A circle at the top of the tube (17)—the edge is seen with cogs—is ruled into 360 degrees and fractions of degrees, on its surface, and is fixed to the tube, and also to the telescope. The whole top from 22 to 23 turns completely around by turning the screw left of 20. Just below 21 are two spider webs crossing the field of view of the lens, carefully protected in a brass cell. One is fixed and the other movable, while both turn when the whole top turns. The webs are invisible when looking at the night sky. So they must be illuminated by the lamp (19), which shines on a mirror, not seen in cut—it is just behind the lamp—and this reflects the light to the webs under 21, and they look

like silver. Figure 22 is a weight to balance the lamp. There are two ruled screw heads to the right of 20. One shows a whole turn, and the other fractions of a turn of the screw that moves the webs. The astronomer must find by trial on the stars the value of one-hundredth turn, and so on. It is an instrument of great power, and has enabled man to unlock doors of hitherto inscrutable labyrinths in space.

The micrometer (cut 78) is Clark's, and is so much superior to early forms that comparison is useless.



Cut 78A. Heliostat, Adjusting Mirror and Spectroscope in Lowe Observatory.

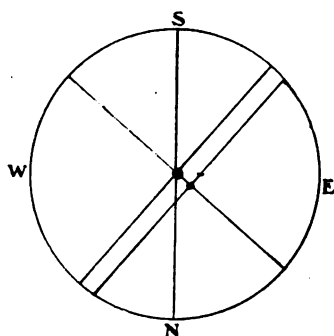
If the eye is placed at 21, a scene of beauty (cut 79) is on display, which is a field of view where a double star is being measured. The webs are represented as turned in two directions.

The webs, wide apart, are shown bisecting the large star and its smaller companion, and their distance apart is read on the edges of the external circle. The webs—close together—measure the angular position of a line joining the two stars with the meridian N. S. in cut, for the place of the celestial equator is

always known from the diurnal motion of the stars across the field, and is shown E. W.

Now watch these stars for say from ten to twenty-five years, making careful measures of their angle with the meridian, and their distance apart each time, perhaps once a year. If the distance and angle is the same at every observation, it is concluded that the star is not a binary; that is, they do not revolve around their common center of gravity. If they do not, then they are a first-class pair for use in a trial to see if they suffer any displacement, looked upon from opposite sides of the earth's orbit, at intervals of half a year.

In 1669, Hooke tried the star Gamma Draconis for six months and found a parallax of 29 seconds! This would make its dis-



Cut 79. Field of a Position Micrometer.

tance only 7,000 times that of the sun. Parallax means how great an angle would be made by the distance of the earth from the sun, to a person standing on the star and looking this way, with a micrometer to measure it. Picard measured the giant star Alpha Lyræ, and could not find any parallax. That is, the distance from the earth to the sun would appear as nothing if seen from that star. Then Flamsteed, with untiring zeal, measured the polar star from 1689 to 1697, and concluded that its parallax was

40 seconds, from which its distance would be small, 5,100 times that of the sun. Then came Cassini, who proved that all the displacements of stars deduced by Hooke and Flamstead, after years of severe labor, were not due to the motion of the earth. The shifting of our particle of dust, the earth, had absolutely no effect on the stars, although it shifts 186,000,000 miles. This blow was crushing, hope sank out of the hearts of astronomers, for how tell the distances of the stars? An impenetrable wall stood squarely across the path of man's advance, and a period of gloom set in.

XXX.

RENEWED EFFORTS TO FIND STELLAR PARALLAX.

"There is one universal soul diffused through all things."—Pythagoras, Greece.

Tune your ear
To all the wordless music of the stars
And to the voice of Nature, and your heart
Shall turn to truth and goodness, as the plant
Turns to the sun.

—Ella Wheeler Wilcox in her wondrous poem "Progress."

After Cassini upset the observations of Hooke and Flamsteed, about the year 1698, the problem of measuring stellar distances was seen to be the greatest that ever confronted the indomitable spirit of man. But none came able to grapple with the great undertaking from 1689 until 1725. Men shrank and faltered thirty-six years.

Then came Molyneux, an amateur. He had made an instrument, a zenith sector, for observing near the zenith only, of great accuracy, the finest yet constructed, and on December 3, 1725, made his first observation on the star Gamma Draconis, which culminated almost exactly in his zenith, and has this advantage: it is only fifteen degrees from the pole of the earth's orbit, so, if the annual circuit of the earth around the sun made any apparent displacement among the stars, it would be at a maximum nearly in this star.

Molyneux observed until December 17th, when an event that changed ancient astronomy to modern occurred. That eminent astronomer, Bradley, happened to visit Molyneux in his laboratory at Kew, England. He, out of curiosity, according to his own account, observed the star. He found that it was farther south than as observed by Molyneux on the 3d. This was not expected; it was thought that an error had been made in measuring. So on the 20th, both astronomers made the most accurate observations possible with the instrument, and both found that the star was still farther south. Intense surprise filled their minds, for the star was moving in the wrong direction to be caused by the motion of the earth. That is, if the earth's movement had any effect, it was obliterated by this other mysterious shifting of the star. Both astronomers now watched the star with the most absorbing interest every clear night. Its stately march ever to the south kept up until April 30th, when it stopped and remained motionless until the middle of May; then started north and passed the meridian at the same distance from the zenith as on the previous December. It went north until September, when it came to a rest, remained stationary a few days, and then went to the extreme south again, describing a small ellipse whose longest diameter was 40 seconds of arc.

Theories were put forth to account for this new wonder, and none were satisfactory. Bradley set himself to the mighty problem to find the cause, and, like Columbus, put out into an unknown and to him shoreless sea. He had a zenith sector constructed with all the precision of the most skillful mechanics of England. He had it made with a wide angle, so he could get the first magnitude star Capella within its range, for Gamma Draconis is of less than the second magnitude.

It was hopeless to try to find the displacement—parallax of any star—due to the motion of the earth until this new motion in the wrong direction should be completely explained.

An eventful and auspicious day came to Wansted, England, August 19, 1727, the new sector was placed in position, and Bradley began that memorable and now historic and classic series of observations, only surpassed in accuracy by the most modern and perfect instruments. Every favorable hour of every clear night throughout his first year was improved; precious time was not wasted, and Bradley soon found that wobbling of the axis of the earth was not the cause—for it does wobble like the axis of a spinning top. This alone was a great achievement. He next proved that changes of density, and therefore in refraction of the earth's atmosphere at different seasons of the year, were not able to cause the deceptive and illusory motion in the stars. This was another great work. He then tried to find if a plumb line shifted on the earth so as to make the zenith appear to make lateral movement. This he proved untenable. The historian says Bradley "pondered."—Grant's Hist. of Astronomy.

But in 1675 Roemer noticed that when the earth and Jupiter were on opposite sides of the sun, eclipses of the moons of Jupiter occurred 16 minutes and 38 seconds later than they did when the earth and Jupiter were on the same side of the sun—the earth between. He knew that nature's laws are invariable, and that the time of the eclipses did not vary. So he inferred that it took light 16 minutes and 38 seconds to traverse the diameter of the earth's orbit, or 186,000,000 miles.

None of the astronomers had power to grasp this stupendous concept. Such incredible velocities were too terrific, the minds of able men were again overwhelmed, and once more, even mathematicians quailed and their hearts subsided and shrank in the majestic and awful presence of nature. So appalling was this concept of Roemer that none accepted it for more than fifty years, and he died before anybody believed, or even could believe. Professor Young says Roemer was 100 years before his time on earth.

But Bradley, in 1728, after one year of observation, believed.

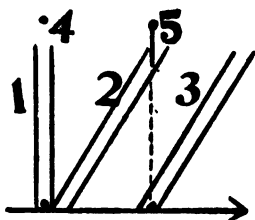
His brain saw, that since light moves 186,000 miles per second, and the earth $18\frac{1}{2}$ miles in the same time, that the combined effect of the two motions would make the star traverse a minute orbit exactly of the same shape as the earth's track around the sun. With feverish anxiety he proceeded to solve the angles resulting from the combinations of these motions to see if the major axis of the star's ellipse would come out 40 seconds in length. One can scarcely imagine with what intense nervous energy the pencil of Bradley flew over the paper. The formulas of trigonometry were instantly called into use, equations solved, and excitement grew as the problem approached solution, with a stupendous truth for its ending.

With a diameter of the earth's orbit 186,000,000 miles, the speed of light 186,000 miles per second, and the velocity of the earth $18\frac{1}{2}$ miles, the transverse axis of the ellipse cut out by a star at the pole of the orbit of the earth is now known to be 41 seconds of arc. That is, Bradley with his sector, almost reached the precision of modern astronomy.

Every astronomer on earth at once adopted Roemer's truth—the speed of light. The recondite physical fact discovered by Bradley has from that moment been considered one of the greatest achievements of the human mind, and is called aberration of light. He proved the velocity of radiance independently of Jupiter's satellites.

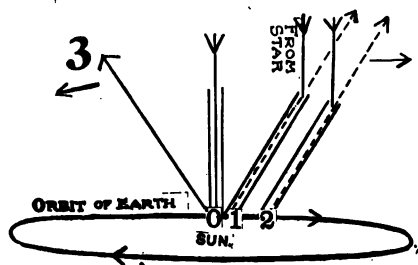
This vast subject ought to be understood; and here is the most elementary explanation. In cut 80, 1, 2, 3 represent tubes, and 4 and 5 falling bodies.

If tube 1 remains at rest, the ball (4) will strike the bottom, but in order that 5 may reach the base, the tube must be inclined to allow ball 5 to enter as shown, and move in the direction of the arrow in position 3, in the same time it takes ball 5 to fall. If the times are equal, it is evident that the falling body will be at the bottom of tube 3.



Cut 80. Aberration of Light.

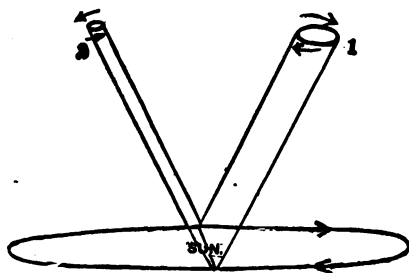
Call 4-5 waves of light, moving 186,000 miles per second, and the distance of the bottom of tube 3 from 1, $18\frac{1}{2}$ miles, and the direction of motion an arc of the earth's orbit, while the tubes are telescopes, then it follows that the telescope must be inclined throughout the year. The star will always be displaced in advance, equal to the inclination of the telescope.



Cut 81. Sun, Earth's Orbit and Aberration of Light.

Cleared in cut 81, showing the sun and the earth's path around it, the earth moving in direction of the arrows. Let figure 1 be the earth's place at the beginning, and 2 at the end of one second of time, with telescopes receiving rays of light from a star. The distance between 1 and 2 is $18\frac{1}{2}$ miles. The telescope (O) is receiving light from the star along its axis at the bottom—or eye-piece—and for telescope in positions 2 and 3, the eye-

end must be drawn back as shown, which makes the object-glass move forward, so that light falling on it shall also fall on the eye-piece. Therefore the star appears to be driven forward in direction of dotted lines, where, it is plain, that if the motion of the earth had any effect on the star, it, the star, would be left behind and appear to move the other way, and be seen in direction of the line O, 3.



Cut 82. Aberration and Parallax.

Simplified in cut 82, where both phenomena are shown.

Figure 1 shows the effect of aberration, and 2, parallax, for the arrows at 1 and 2 are in opposite directions. The ellipses at 1 and 2 are those minute orbits apparently traversed by the star in a year.

The reader must not be in error here, for the lines from opposite sides of the sun, 186,000,000 miles, to the star are drawn parallel. They should come to a very near approach, 41 seconds of arc, in the aberrational ellipse, and to an exceedingly fine point at the parallactic ellipse, since the whole earth's orbit as seen from the nearest star amounts to almost nothing, totally invisible without a telescope, placed on the star and looking this way. The ellipse of aberration even cannot be noticed without a powerful telescope and micrometer, also, it is so very small.

Bradley started to find the parallax of a star and found one of the chief wonders of all ages—the aberration of radiance. But

the stars! the stars! It seemed that it was beyond the power of man to tell their mighty distances, for Bradley, the best astronomer so far had failed. And he said he felt sure that if it had a value of one second he would have detected it. It is known now he could not with his sector. Discomfiture and depression fell upon the minds of the astronomers of Europe. Several tried it, and all failed. Matters went on from 1727 to 1790 with no results, when Sir William Herschel began by observing double stars. He labored long, and instead of finding parallax made a most important discovery—binaries—that is, where two suns revolve about a common center.

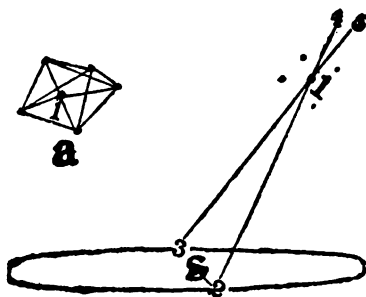
At the opening of the nineteenth century came Piazzi, who tried to measure the distances of the great suns Sirius and Procyon. He made out that the distance of Sirius was one-tenth of what it actually is. Then came the Russian astronomer Struve and found displacements of stars insensible—so far away that the motion of the earth had no effect. This was from 1818 to 1821. In 1835 he watched Vega for six months and made its distance one-half of its real value. All these troubles came from poor micrometers, bad object-glasses and from the fact that refraction in the earth's atmosphere had not been determined with rigid accuracy. Due allowance had not been made for pressure, temperature and water vapor. Now the barometer, thermometer and hygrometer are carefully noted. Other complex motions of the earth too abstruse to be explained in elementary notes had not been found with precision, so failure was inevitable.

BESSEL.

Then the mighty brain of Bessel came to the rescue in Königsberg. He had made an instrument on a new principle (its technical description must be omitted), the heliometer, of surprising accuracy. He did not measure the exact position of the

stars when they passed the meridian, like Bradley and his successors.

Bessel used the method of differences. This must be understood by all who wish to see the solution of the most remarkable work and arduous ever performed by man.



Cut 88. Bessel's Method.

Cleared in cut 83, where the sun and orbit of the earth are shown as before. Let figure 1 be the star whose distance from the sun is sought. Five stars are shown near it, and an enlarged view of them at A. The plan is that of triangulation, the same as that employed on the earth's surface by surveyors. The five stars are at such tremendous distances that the 186,000,000 miles, the diameter of the earth's orbit (2, 3) is nothing as seen from them. Hence these stars appear stationary. All triangles at A are measured during the year, while the earth moves from 2 around 3, and to 2 again, with the greatest accuracy and results recorded. At the end of the year all the angles are solved, and if the angles from each of the five stars, to all the others of the five, are equal to their values in the beginning of the year, proof is had that they have not moved, but if all the angles made by each of the five stars with star 1 are unequal, star 1 has apparently moved. Solving all these triangles, a stupendous result is obtained—the

angle 4, 1, 5 is found! But by elementary geometry it is known to be equal to the opposite angle, 2, 1, 3. The distance from 2 to the sun being known, it is merely a question of simple division to find the side (S, 1), the distance of the star. The radius of the earth's orbit (S, 2, or S, 3), is called the parallax of the star 1, and S, 1, 2 is its angular value as seen from the star—usually the thickness of a spider's web, but really 93,000,000 miles.

The labors of Bessel surpassing those of Hercules continued from 1837 to 1840, on the star 61 Cygni. Bessel used two small but vastly more distant comparison stars, but later observers have used more, and other stars.



The Eclipsed Sun.

HENDERSON.

While Bessel in Königsberg was reducing his observations, Henderson in London was deriving final deductions from researches made by him on Alpha Centauri in 1832-3 at the Cape of Good Hope, South Africa, which star is the nearest neighbor the sun has, so far as at present known. Thus Hooke began the great work of finding the distance of a star in 1669 and one was found in 1839, a continuous struggle during 170 years. This labor surpasses all other work of human hands. The Pyramid of Suphis cannot compare with it, for astronomers toil as none others among men toil, with brain, nerve and gross body. Here is the all-important number—that valued number that cost more than any other, representing now more than two centuries of skilled labor; that magic number, that sounding line sunk in space, that unit of stellar measures, that precious key whose power is to unlock the labyrinth of the sidereal universe; that number whose value cannot be compared to anything in the possession of man is now known to be, from the latest determinations.

.75 SECOND OF ARC.

That is, go to Alpha Centauri, with a telescope of high power and perfect micrometer, and look this way. Then the distance from the earth to the sun will shrink to only three-fourths of a second!

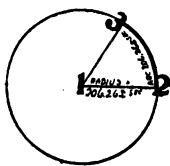
The word second must be explained. Take a child's marble, a ball one inch in diameter, to a distance of three and one-fourth miles, and its angle at the eye will be one second. A powerful telescope would be required, and a still more powerful micrometer to measure it. Since the parallax is only three-fourths second, the marble must be moved four and one-third miles away to appear to be that of angular diameter. It is no wonder that 200 years were consumed.

Bessel and Henderson both made their parallaxes too large,

and the stars too near, for the greater the parallax the less the star's distance, so it is only lately that the value, .75 second, was obtained by the most perfect instruments ever made. But now comes the standing marvel of the centuries—photography—for all the stars near the one being measured, as in Bessel's problem, are photographed, and the negative measured with a microscope at leisure. Since the parallax is only three-fourths second, the marble must be moved four and one-third miles away to appear to be of that angular diameter.

HOW TO TELL THE DISTANCE OF A STAR. . .

This can be done by using a radian, without resort to sines, cosines, tangents, etc.



Cut 84. A Radian.

Cut 84 shows a radian, the angle 2, 1, 3.

A radian is the angle measured by an arc, equal in length to the radius of any circle. In cut 84 the line 1-2 is the radius, then if the arc of the circle from 2 to 3 is $57\frac{1}{3}$ degrees its length is the same as the radius. Hence if a person stands at figure 1 and sees a sphere or straight line that fills one-fifty-seventh of the curve 2-3, its angular diameter is one degree, and no matter what the real diameter of the object is, he knows that it is $57\frac{1}{3}$ times that diameter in distance. In a circle there are 1,296,000 seconds, and in $57\frac{1}{3}$ degrees there are 206,265 seconds; and if the observer measures any object with micrometer whose angular diameter comes out one second, he knows that its distance is 206,265 times its actual diameter in miles, or inches.

In two hundred years men found that the angular value of the distance of the earth from the sun as measured by a micrometer placed on the nearest star is .75 or, three-fourths of one second; so 206,265 divided by three-fourths equal 275,202, the number of times the star is more distant than the sun.

XXXI.

THE SIDEREAL STRUCTURE.

'Twas the morning of time
 When yet naught was;
 Nor sand nor sea were there,
 Nor cooling streams;
 Earth was not formed,
 Nor heaven above;
 A yawning gap there was.

—Grand "Hymn of Creation," the Edda, Scandinavian Scriptures.

As yet the world was not,
 And Chaos wild
 Reigned where the heavens now roll
 And where the earth now rests.

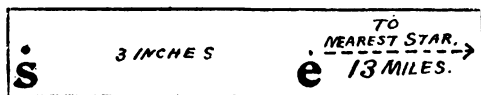
—Milton.

INTERMINABLE SPACE.

In cut 85 let S represent the sun, and E the earth, distant three inches; then the distance to the nearest star is thirteen miles. This distance is so stupendous that the mere attempt to think about it is crushing to the mind. Here are times to traverse the mighty void:

Train of cars, one mile per minute, 47,528,000 years; the earth on its orbit, $18\frac{1}{2}$ miles per second, 42,823 years; light, 186,000 miles per second, 4.26 years. And upon arriving at the star the traveler has not more than made a start from home, has scarcely

passed from his front gate, for the heavens as seen from there would appear sensibly the same as from here, he would not know he had moved, and could not tell which star was his own sun, for they all would look as much alike as they do now, our sun being merely a small star, similar to all the others.



Cut 85. Distance From Sun to Star.

Nature is incredibly lavish with her space, and astronomers are unable to see why it is necessary for all suns to be separated by such unfathomable distances. For if our sun and Alpha Centauri were to approach to one-eighth their present distance apart, it is doubtful if the planets revolving around each would be perturbed by any amount capable of being detected by a micrometer. A number of microscopes have been made that show particles requiring 100,000 side by side to occupy one inch. Each one of these is larger, proportionately, to one cubic inch than the earth is to space revealed by modern telescopes.

If the universe whether finite or infinite is peopled with intelligent beings, they have not heard of the earth nor the human race. We are unknown, and if the earth and every inhabitant be instantly annihilated, the little event would be entirely unknown to space, and not the slightest difference would be made, except minute disturbances in our own local solar system. And should the sun and all the planets be destroyed in one second, no difference whatever could be detected in the sidereal edifice. Only a professional astronomer on some planet near an adjacent sun would miss it, and not he, unless he had an accurate star catalogue and made close examination among its millions.

NUMBER OF THE LUCID STARS.

By lucid stars is meant those visible to a good eye on a dark clear night without optical aid. By actual count the number is 6,874, from the brightest to the sixth magnitude—the extreme limit, for the seventh magnitude cannot be seen without a telescope. Half, or 3,437, are above the horizon at the same time. But fourth, fifth and sixth magnitudes cannot be seen when within fifteen degrees of the horizon, owing to the increased depth of air, water vapor and dust, even on a “clear” night. So the maximum visible at the same time is about 2,000. But an opera glass brings the seventh magnitude into view and vastly increases the number.

Magnitudes are not based on size, for all the stars are points without diameter even in the largest telescopes, but on their apparent brightness. The leaves of the trees in a forest vary by insensible gradation from bud to the “sere and yellow leaf,” and stars vary from the faintest in the Yerkes telescope to the brightest of all, Sirius. Still, astronomers have classified all by magnitudes on the following photometric scale: An average star of the first magnitude is $2\frac{1}{2}$ times more brilliant than one of the second, and one of the second is $2\frac{1}{2}$ times brighter than one of the third, and so on in geometrical progression, the constant multiplier being $2\frac{1}{2}$, and by continuing to the sixth magnitude it comes out that it takes 100 stars of that magnitude to give as much light as one of the first magnitude.

All the stars visible from Harvard College Observatory have had their light measured by a meridian photometer, devised by Professor E. C. Pickering. The light sent hither by Polaris, the North star, is used as the standard of comparison. The telescope is set east and west, and has two object-glasses. In front of each is a mirror inclined at an angle of 45 degrees. It is clear that these mirrors must be in the meridian, if the telescope makes a

right angle with it. One mirror reflects the light from the polar star into the telescope, while the other reflects the light from any other star that may be crossing the meridian, the two lights falling side by side for comparison by a Nicol. The standard first magnitude star is Aldebaran, the bright star in Taurus, the first in the V shaped cluster, the Hyades.

Bright as it is, its distance is 1,778,000 times greater than that of the sun, or 1,778,000 multiplied 93,000,000 miles.

What an inconceivably hot and large sun it is! Should the earth come anywhere in its vicinity it would be turned to gas so rare that it would be invisible. And the stars Sirius and Canopus are very much brighter and hotter than Aldebaran. The distance of Canopus just visible over the waves of the sea south of here, but invisible from San Francisco, is so enormous that the swing of that pendulum the earth, of 186,000,000 miles, is absolutely insensible as seen from that giant sun; that is, the parallax of Canopus is 00! What brain can imagine its terrific heat or dimensions?

Since Sirius and Canopus are brighter than Aldebaran—the star that it has been agreed to call first magnitude—they must have negative magnitudes. Thus Arcturus sends us twice as much light as Aldebaran, so its magnitude is 00, and Sirius—1.4.

Thus it would take 10,000 stars of the eleventh magnitude and 1,000,000 of the sixteenth to emit the same quantity of light poured forth by the mighty Aldebaran. The 36-inch telescope of the Lick Observatory brings into view, stars between the sixteenth and seventeenth magnitude, and the 40-inch Yerkes reveals to human vision down to the seventeenth, while the 16-inch in this observatory brings forth from space the fifteenth. But the air is so nearly chemically pure here that in all probability faint stars to the magnitude of fifteen and one-half can be seen, strewn like faintly sparkling gems on the awful blackness of infinite space. Since the ratio of progression of stellar light is $2\frac{1}{2}$ a table can

be continued from the visible to the invisible regions, if there are stars beyond the powers of the 40-inch.

Magnitudes.	Numbers of stars.
First	20
Second	65
Third	200
Fourth	500
Fifth	1,400
Sixth	5,000
Seventh	20,000
Eighth	68,000
Ninth	240,000
Tenth	720,000
Total	1,055,000

These have been counted with more or less accuracy, notably by Professor Gould. There are some irregularities, for 65 multiplied by $2\frac{1}{2}$ equals 162 as the number of third magnitude, while there are 200. However, carrying out the formula to the end of the seventeenth magnitude, their number would be 440,000,000. The total in the table to the end of the tenth is 1,055,000; so, by adding successive numbers from the end of the tenth to that of the seventeenth, the result is 733,000,000.

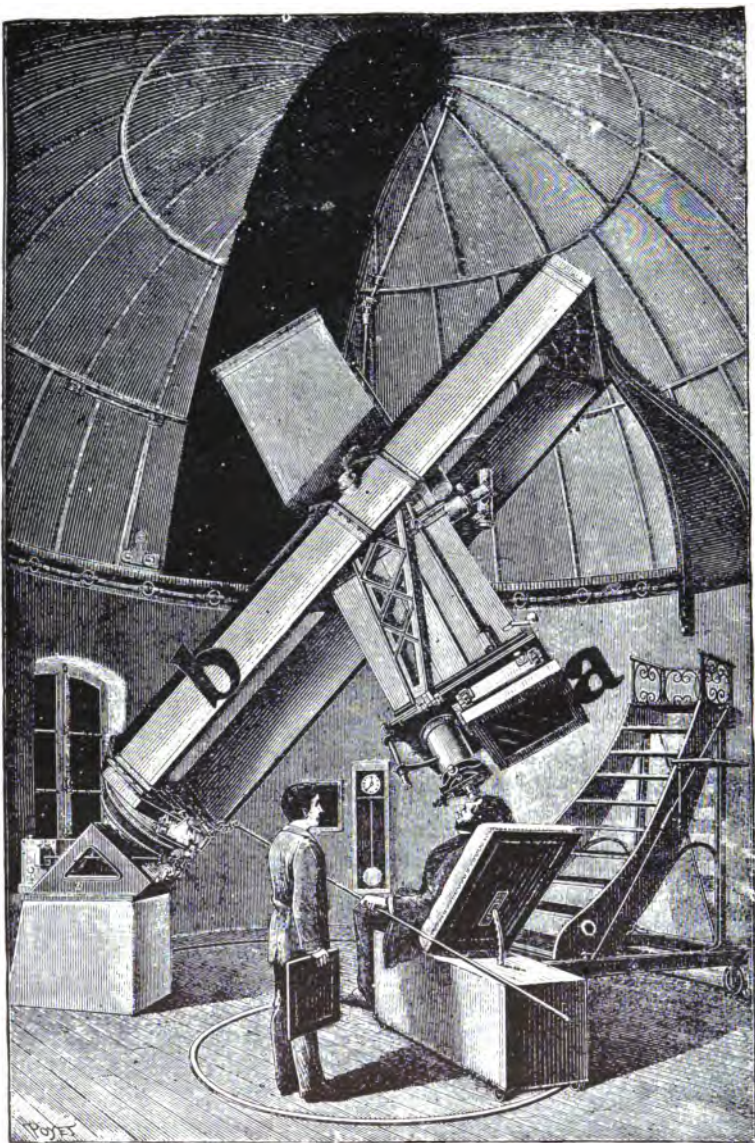
A world's council of astronomers was held in Paris in 1887. An agreement was made to photograph the entire celestial vault for future generations. The gigantic work was assigned to eighteen observatories in different parts of the world, so all the sky could be included. All the telescopes were to be 13-inch, all alike, and the tele-cameras were also alike, the plates being therefore similar.

Cut 86 shows the telescope and tele-camera in Paris. Infinite space studded with diamonds, sapphires and rubies is seen through an opening in the dome. One of the famous Henry brothers is centering the telescope on a region of the sky to be graphed, while the other is bringing a plate to be inserted in the plate-holder of the camera, as shown at A. The inclined frame (B) holding both the telescope and the tele-camera, is placed parallel to the axis of the earth with great accuracy—that is, it is pointing to the north pole. The driving clock is started as soon as the plate is pushed in. Exposure is then made, and the clock turns the whole apparatus west as fast as the earth rotates to the east, so the stellar images formed by the object-glass of the photographic telescope shall fall constantly in the same place. Exposure has been made from one to eight hours, the plate storing the radiance, thus bringing countless thousands of stars into view, invisible in any telescope, all because the eye does not store energy. The object-glass of the telescope—made for seeing—is unfit for graphic purposes, for the waves that oscillate with rates to “shake down” the silver salt are too rapid to be seen, so two objectives are in the upper end, one in the tele-camera and the other in the telescope, each having a different focal length.

GRAPHIC RESULTS.

The thirteen telescopes were nearly like this one, and wrought a work beside which pyramid, palace and obelisk is antiquity pale and faint.

The total number of plates required to graph the entire sidereal vault is 22,054. Two sets were to be taken, one with exposure long enough to get images of all the twelfth magnitude and the other all down to the end of the fourteenth. The stars on the first set were all to be measured as to position and then catalogued. When finished the plates will show between two and



Cut 86. Henry Brothers' Telescope, Paris,

three million stars. It was agreed later to make three exposures of each plate, so shifted that each star shall appear at the three angles of a minute triangle—a plan which eliminates all errors.

Reports are in from many of the observatories, and 16,000 graphs have been secured. Some plates show 5,000 stars. Many in different parts of the heavens have been counted, and a series of averages computed. There are 30,000,000 suns to the twelfth magnitude. Part of the plates exposed longer for the fourteenth magnitude have been treated and the sum indicated is 50,000,000. Thus photography in a few years has performed a work that **would take centuries** of labor by all the astronomers of the world to complete. Other graphs with still longer exposure have been secured, counts made, estimates formed, the calculus of probabilities applied, and computations reveal that the probable number of stars visible on all the plates to the end of the seventeenth magnitude is not less than 100,000,000.

Professor Simon Newcomb says: "The photographic maps now being made probably show more than 50,000,000, perhaps 100,000,000, possibly twice that number." This includes all that possibly can appear on the best plates with all night exposures, and may include the eighteenth magnitude if there are any. But as shown, by carrying out the formula of progression to the seventeenth magnitude, using the standard ratio of 2.5, the number came out 733,000,000. From this it follows that there is actually a thinning out of stars from the thirteenth to the seventeenth, else they are not as bright, or if the 733,000,000 exist, their light is quenched in space, by an absorbing medium, or by cosmic dust, or by the primordial corpuscles. In absence of any of these causes it is not known that radiance, that affects plates most, can go on vibrating 763 million million times per second indefinitely. In these notes, the number of suns that will finally appear when all the plates are measured will be taken as falling between 100 and 125 million.



Cut 87. Professor E. E. Barnard's Famous Camera — The Willard Lenses.

In cut 87 is the camera with which Professor E. E. Barnard took his remarkable series of graphs of the Milky Way.

XXXII.

THE STELLAR UNIVERSE.

"When the heaven above and the earth below were as yet unnamed, the abyss and the billowy sea were the beginning of things."—Chaldean Hymn of Creation.

If a meteor half an inch or more in diameter falls toward the earth, it rushes with great velocity through the air and friction liberates intense heat. The meteor is dissipated into very fine dust, which may take a month to reach the earth's surface. But at the instant of disintegration, the most brilliant flash of light is seen. With small meteors the light shines from one to five or six seconds. The longer, the more heat, and therefore the more light. Thus from this observatory on November 15th, 1901, a large meteor separated light that remained fourteen minutes.

The total light-emitting period of all suns, bears about the same proportion to their entire duration that this fourteen-minute meteor's flash bears to its duration. Light and also heat are but mere episodes in the evolution of matter. In the twenty-seventh chapter it was shown that the sun's light-giving epoch is more than 22,000,000 years, a time comparable—with its mass—to the meteoric fourteen minutes, and its mass.

It is now known and will be proven in a subsequent chapter, that the number of cool dark bodies, like the earth and Mars, and larger still—dead suns—is so inconceivably greater than living suns that they cannot be compared, even. The sidereal edifice is

of the most incredible antiquity, and only 100,000,000 live suns now remain, mere funeral tapers to illuminate with their tiny firefly light the cheerless and solitary paths of darkened suns and frigid worlds. Evolution is stamped indelibly on the mighty facade of the cosmical temple. The process is continuous, and is now in an active state. For that marvel of all ages, the telespectroscope, reveals suns in every possible phase of evolution, from the most archaic gas to expiring globes.

The entire history of a sun is as well known as the evolution of flower from seed to frosts of death. A human eye now rests on suns almost every minute of the year. Not one can make evolution without being instantly graphed. And the most profound secrets of nature are wrested from her reluctant hands, and every action stored on the wondrous sensitive plate. On every clear night in the year, perfect graphs are taken at the Harvard College Observatory in Cambridge, and also at its branch observatory high on the mountains in Arequipa, Peru, S. A. Most of the observatories of the world now graph at every favorable time. At Harvard a building is filled with these precious negatives. They should be placed in steel vaults in air-tight cases and enclosed in a rock-hewn pyramid or temple to survive another glacial epoch.

Future astronomers in 10,000 years could make new graphs and compare, to see what phases of evolution had been passed in the meantime. If, indeed, the negatives would keep that long. If not, new prints should be made from time to time and deposited until the ice again comes and ends the work. Or, perhaps, in the nebulae, 10,000 or 20,000 years would not be long enough to make changes prominent enough to be seen without a microspectrograph. Evolution in well-advanced suns, however, could be detected, for light from the mighty upheaval last year in the new sun in Perseus could be seen with the unaided eye. This was doubtless an explosion or collision. Evolution proper is slow.

PLAN OF THE PALACE OF THE UNIVERSE.

From the best and most comprehensive soundings let fall in space, it is thought that the structure of suns, planets and nebu'æ, is neither a sphere nor a disc shaped like a bi-convex lens; but in form more like a watch. The rim, hinges and stem lie in that mighty foundation, the Milky Way, while the axis of the watch, carrying the hands, corresponds to the axis of the cosmical structure, the ends being the poles of the galaxy.

If the entire structure is in revolution then the belt of starry hosts is the equator, tending to expand, while stars at the poles would come in, still more increasing, flattening into a lens-shaped mass of suns.

It is not known if the vast body is in rotation, since accurate astronomy is not 100 years old yet. In 10,000 years astronomers may be able to find rotary motion if it exists.

At all events, whole myriads of suns, single, double, triple, multiple, condense, pile in, crowd together and congregate in that stupendous band, encircling the entire congeries of flying bodies. Nebulæ mostly gather round about the galactic poles. These are immense volumes of gas whence suns are seen in evolution in all stages. But when complete suns are developed they seem to gravitate in the direction of the plane of the galaxy, bisecting the cosmic structure. And a majority of the first magnitude suns lie somewhat near the plane of that mysterious ring, while our own modest sun also is thought to be near the plane of the magic circle.

For in many directions the suns are in such colossal heaps and depths that there is scarcely room for more on graphic plates. The distance between each, however, is doubtless as great or greater than that separating our sun from its neighbors—25 trillion miles—except in the case of binaries or close clusters.

DISTANCE OF OUR NEAREST NEIGHBORS.

Man has no hope of ever being able to measure the distance of more than a few near-by stars. Nothing can be had thinner than a spider web, and it would not be possible to use a finer in micrometer, if such a fiber should be found. Unless new discoveries or more accurate measurements in the line of sight by new spectroscopes of unheard-of power, or by some undiscovered device in photometry, the vast distances of more than perhaps 50 to 100 stars will never be known, because the base line, the diameter of the earth's orbit, 186,000,000 miles, is so minute as to escape detection in any microscope, placed on the distant stars. Unless, indeed, some incredibly large objective corrected for graphic waves should be constructed, and sensitive plates with much finer grain than silver salts, to store almost insensible images of faint stars and make perceptible the still more minute displacements among the tiny points due to the annual swing of the earth. For the entire area enclosed by the orbit of the earth as seen from some of the stars would be hidden by a particle in a microscope placed on these stars and looking this way, comparable in size with the particles of black pigment in this ink. An astronomer on Neptune could measure the distances of more stars, for his base line would be in length 5,580,000,000 miles, and might be detected in a micrometer placed at not extravagant stellar distances.

Here is a table of parallaxes and distances of a few well measured stars:

DISTANCES OF NEAREST STARS.

Names of Stars.	Paral- laxes in seconds of Arc.	Distances sun's distance being 1.	Dist. in trill- ions of miles.	Times in years for light to reach the earth.
Alpha Centauri	0.75	275,000	25	4.26
61 Cygni	0.45	458,000	43	7.20
Sirius	0.38	542,800	50	8.50
Procyon	0.27	764,000	71	12.00
Altair	0.20	1,031,325	94	16.00
O2 Eridani	0.19	1,085,600	100	17.00
1830 Groombridge	0.13	1,586,650	147	25.00
Vega	0.12	1,718,900	158	27.00
Aldebaran	0.10	2,062,265	191	32.00
Capella	0.10	2,062,265	191	32.00
Polaris	0.07	2,946,640	276	47.00
Arcturus	0.02	10,313,250	950	160.00

This is an impressive display of facts and figures. Thus the nearest star, Alpha Centauri, is brighter than the standard first magnitude Aldebaran, while the next nearest, 61 Cygni, is only of the fifth magnitude, requiring a clear, dark night to see it without a lens. Sirius, the most brilliant star, is just twice as far away as the nearest.

Look at the vast distance of the pole star—276 trillion miles—and the colossal Arcturus. How approach this majestic sun with human speech? It pours forth 6,200 times the quantity of light emitted by our little sun. Many astronomers have despaired of ever finding its distance, but in very recent years the mighty problem has been attacked with renewed energy, patience and skill, notably by Dr. Elkin. Astronomers are agreed that its parallax is about the one-fiftieth (1-50th) of a second. That is, go to Arcturus and look this way with the most powerful microm-

eter made, and the distance from the earth to the sun—93,000,000 miles—would occupy one-fiftieth of a second in the sky.

Take a child's marble one inch in diameter to a distance of 161 miles, and it will appear to fill one-fiftieth of a second as an arc of a circle. And modern astronomers must measure such quantities as these or remain ignorant of the dimensions of that part of the universe close by home.

But the mighty sun Canopus—go to it, turn and look this way; the distance from the earth to the sun is absolutely invisible in any microscope that human hands can ever hope to make. Canopus is brighter than Arcturus; and a line 93,000,000 miles long, as seen from Canopus, is less than the diameter of a spider's web.

But great things are now being done by photographing the heavens, and then measuring the inconceivably small displacements of the stellar points with a high-power microscope, under a system of rectangular co-ordinates, also photographed in small squares, like cross-ruled paper.

The stars are graphed by a long exposure, and then fine crossed lines are graphed on the same plate by a second exposure, and numbered. Thus any star can be found as well as a house in a city block. The plates are measured under a microscope in a measuring engine, and if any displacements are noted in subsequent graphs the amount is determined.

Thus parallaxes of the stars are now found by machinery instead of by the old-fashioned, laborious and tedious methods.

A most extensive series of measures is now being made at Harvard College Observatory—notably by Mrs. Fleming and Miss Maury, the collection of plates now numbering more than 110,000. A succession of important results has followed, for proper motions of stars have been discovered, also variables, and new stars as well. The photograph is revolutionizing all departments of practical astronomy, for Professor Pickering and his skilled as-

sistants at Harvard and Arequipa, graph the entire heavens, once each month! He superposes subsequent graphs by months, so, if any star has moved, it will be instantly noticed, for their images on the two plates under the microscope will not exactly coincide.



Cut 88. Double Cluster in Perseus.

Some regions in the sky are rich in stars, and an idea of the power of modern instruments may be had in cut 88, the double cluster in Perseus, where no separate stars appear to the unaided eye.

All are familiar with the Seven Stars or Pleiades. With 17h. 30m. exposure on nine (9) nights, a region round about, four

square degrees in area, shows almost 7,000 stars on the plate. The stars often gather in clusters, as may be seen in cut 88.

The Perseid cluster is made up of fine stars—many regions in the Milky Way are hundreds of times finer—as in cut 89. Cut



Cut 89. Photograph of Milky Way, taken at Sydney, Australia.

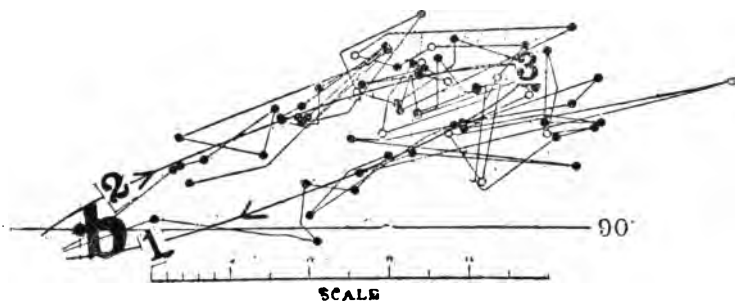
89 is of a photograph of a rich region of stars in the Milky Way, taken at Sydney, Australia, all of which were condensed and broken up from one mass of primordial, ultra-gaseous corpuscles—"bodies much smaller than 'atoms.'"

XXXIII.

BINARY SUNS.

"It is thus by an alternative waking and rest, that the immutable Being causes to revive and die eternally all existing creatures, active and inert."—From Laws of Manu, book 1, Shloka 50, Hindu.

Herschel in his life-long and tireless search for stellar parallaxes, not one of which was he ever able to find, owing to his lack of accurate micrometers, and knowledge of the exact value of refraction of light in the earth's air—nevertheless made another discovery almost equally important—binaries. These are where two suns revolve around their common center of gravity, in regular orbits, nearly always ellipses. And their study has greatly expanded all concepts of the sidereal universe and its ancient history of evolution. So surprising have been the results of this investigation, that modern astronomers are amazed at the work of their own hands, while the ablest now living would have thought them beyond human powers, had they been predicted fifty years ago. The revelations due to binary, triple and multiple suns should be understood by all who admire nature or who care to know what the brain of man is really capable of doing in this age of trained research. As soon as the two Herschels, Struve and other astronomers found that vast incandescent suns were in revolution around each other, or rather around gravitational centers, world-wide interest was at once awakened and many skilled observers began extensive series of most precise measurement.



Cut 90. Binary—BC—of the triple Sun Gamma Andromeda.
Positions From 1842 to 1897.

Gamma Andromeda is a triple sun, the largest star being A, the next B, and the faintest C. The star B is shown at B in cut 90, while all the black dots are positions of the star C, measured from 1842 to 1897—55 years. The star A is 10 seconds of arc distant from B, and is not shown in cut 90, for a distance of 10 seconds, small as it is, would be too large to appear in this wondrous diagram, where the length of the scale below is only half a second.

A sphere one inch in diameter to subtend half a second must be at a distance of $6\frac{1}{2}$ miles. The black spots are nearer the mark than rifle shots by an expert. These small errors were not so much in the micrometer as in the earth's air. The network of angles from dot to dot has been solved, and the result is the curved line, 1, 3, 2, a very eccentric ellipse, the mathematical orbit of the star C around B, or, strictly, around the center of gravity of B and C, for B also traverses a minute ellipse the same in shape of that moved over by C, once in 55 years. The letter C does not appear, it may be imagined to be anywhere on the ellipse, 1, 3, 2.

It will be noticed how eccentric the orbit is, that is, its deviation from a circle, which is 0.82, while that of the orbit of the

earth around the sun is 0.017, only one-fifth as great. The consequence is that when the flying sun C moves from 1 to 2, around B, in the direction of the arrows, it moves with great speed to prevent falling on B, while the velocity is slow at 3, far away. The nearest approach to B is called periastron, while the most remote position is apastron.

This binary has just made one circuit since discovery, and five years on another. The two stars B and C do not revolve around A, the large star, 10 seconds away, so far as detected, but they all move in the same direction, side by side, through space, which movement of stars is called proper motion. The star C passed periastron in 1892.

It is not necessary to watch a binary through a complete revolution, for, give an arc of an ellipse to a geometer and he can compute the entire curve. And some of the times of revolution are known to be more than 1,000 years.

Human beings could not live on the planets revolving around either of these suns, B and C. For when C came near B the inhabitants would be between the suns—and there would be no night. All water would be boiled into steam and life expire. As periastron approached, the people on worlds round about sun C would notice sun B growing rapidly larger. And then larger and hotter still, and the heat and light would soon become intolerable.

Milton's concept of living beings chained to incandescent, porphyritic stone, would fail here. The planetary heavens would burn as heated brass, and the heats of Pelee and Souffriere would pale and faint. The surfaces of the inhabited worlds would become parched, cracked and seamed—steam, smoke and deadly gas would fill the suffocating air.

People near sun B would behold C rushing through their torrid sky with frightful speed, growing larger and hotter every minute, and the sinister sun would appear in most portentous

aspect. For a world happening to be between the suns, rapid death would fall on plant, animal and man, or a still higher type. The eventful day of periastron would occur every 55 years. It is doubtful if life can be on worlds about suns whose orbits have eccentricities greater than one-half, for even then, the variation in heat would be tremendous. The distance of the system of Gamma Andromeda is unknown.

ALPHA CENTAURI.

This majestic pair of suns, our nearest neighbor, revolves in 81 years. The eccentricities of their orbits are one-fifth, so, beings with no more intelligence than men might adapt themselves to the great variations of climate.

FINDING MASS OF BINARY SUNS.

Kepler discovered one of the most stupendous laws that the brain of man has yet detected in the hidden recesses and labyrinths, dim corridors, obscure passages and caves under nature. This law rules all that fraction of the sidereal edifice near enough to be seen in telescopes, however powerful.

Law: The squares of the times of revolution of bodies around their common center of gravity are to each other as are the cubes of their mean distances from their center of motion.

Application of Law: The time required for the earth to revolve around the center of gravity of the earth and sun is equal to one (1), and the earth's distance from that center equals one (1). The observed time for Jupiter to make circuit is equal to 11.86. Now 11.86 squared is 140; and the cube root of 140 is 5.2, but that is the known distance of Jupiter from the sun, found in other ways. That is, Jupiter is 5.2 times farther from the sun than the earth is, or 483,000,000 miles. This law enables men to tell the quantity of matter in suns, so far away that the mind is unable to form any concept of the distance.

A quantity of matter equal to that in the sun and earth combined is by the action of gravity able to force a body at the earth's distance from the sun to go around it in $365\frac{1}{4}$ days to prevent falling into the sun, for the centrifugal tendency equals gravity.

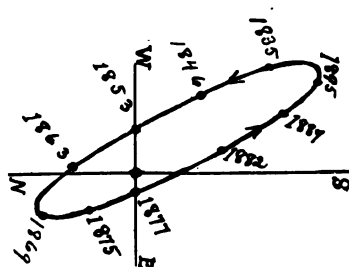
Since gravity depends on quantity of matter, or mass, it is clear that there must be a strict relation between the motion of the earth and the sun and between the Alpha Centauri and its revolving sun. The combined mass of these two suns is able to force one of the suns at a distance from the most massive, 21.33 times as great as that of the earth from the sun, to revolve around it in 81 years to prevent falling. Then the distance, 21.33 cubed, equals 9,664, while 81 squared is 6,561, and the quotient of these numbers is 1.5, so the quantity of matter in both suns is known to be one and a half times greater than that in our sun and earth. Since the mass of the earth amounts to nothing—almost—it is said the suns in the Centaur are $1\frac{1}{2}$ times more massive than ours. Their distances apart—21.33—is obtained from the apparent semi-major axis of the orbit, which is 16 seconds of arc. This, divided by the parallax, 0.75 of a second, equals 21.33 times 93,000,000 miles, equals 1,984,000,000 miles, a little more than our planet Uranus from our sun. Thus given three quantities the distance to these two suns—twenty-five million million miles—their distance apart, 21.33 times greater than that of the earth from the sun, and their time of revolution—81 times greater than that of the earth—then the finding of their combined mass is a mere question of arithmetic. But it took 120 years' severe labor to find the distance, and it took Kepler 17 years' unheard-of work to find his mighty law.

Cut 91 shows the orbit of the binary, Alpha Centauri.

THE SUN SIRIUS.

About fifty years ago it was found that the regular motion of that, to us, brightest of stars, Sirius, was disturbed. Instead of

traversing a regular curved line on an ellipse, or a straight line through space, due to our own proper motion, it deviated first to one side and then to the other. It was watched with interest by many astronomers. They all agreed that the perturbation was caused by either a small sun revolving around it or a dark world. Auwers then applied that mighty power, mathematics, computed the orbit of the unseen body, and told its direction from Sirius. And then A. G. Clark discovered it in exactly the predicted place with his new telescope, now in the observatory at Evanston, Ills.



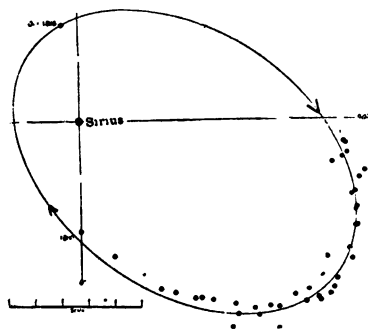
Cut 91 Orbit of Our Nearest Neighbor, Alpha Centauri. Period 81 Years.

This was the beginning of that great branch, the "Astronomy of the Invisible." The new body proved to be a small sun, for it shines by its own light, where planets are seen only by borrowed radiance.

MASS OF SIRIUS AND ITS COMPANION.

For several years the parallax of Sirius, as determined by Professor Gill, has been adopted as 0.37 second of arc; but now comes W. S. Adams with a spectroscopic parallax of 0.21 second (the mean of these is 0.29 second), and with this let the mass of both suns be computed. A radian—206,265 seconds—divided by 0.29 second equals 700,000. That is, Sirius is 700,000 times farther from the earth than our sun is.

In cut 92 is shown Professor N. M. Mann's carefully computed orbit, and its semi-major axis is given by him as seven seconds (Newcomb gives five seconds), which is the apparent value seen from the earth; the real value, being seven, divided by 0.29, equals 24; thus the companion is 24 times farther from Sirius than our sun's companion, the earth, is from it. Kepler to the rescue, for the distance, 24 cubed, is 13,824, and the time, 50 years, squared equals 2,500, the quotient of the two numbers being 5.5, so the quantity of matter in Sirius and its neighbor is



Cut 92. Orbit of Sirius.

$5\frac{1}{2}$ times that in our sun and earth. If the value, five seconds, as given by Professor Newcomb, had been used, the mass would have come out smaller, for less matter would be required to cause the small sun to make circuit around Sirius at a less distance in the same time.

The error is less than those made in shooting at the Harvey-ized steel targets in the navy-yards. Life could not exist a minute on planets around the revolving sun, even when at its mean distance of 1,232,000,000 miles, or less than that of Uranus from the sun.

There are over 200 telescopic binaries known—that is, widely

separated suns—whose distances apart are great enough to be seen in the best telescopes. But new and more magnificent arrays of splendid binary and ternary suns are shown in the spectroscope. Here is a table of short-period telescopic binaries:

Names of Suns.	Periods in years.
Kappa Pegasi	11.42
Delta Equulei	11.45
883 Burnham	15.80
XI Sagittarii	18.85
Rho Argus	22.00
85 Pegasi	24.00

From these short periods of revolution, the times extend to as high as 1,500 years. Thus, from Professor W. J. Hussey's catalogue, Lick Observatory, these periods are taken at random: 135, 200, 115, 118, 93, 182, 190, 107, 260 and 198 years, while the star Zeta Aquarii is 1,500 years.

Some astronomers devote their entire life-work to double stars; thus Professor S. W. Burnham devoted thirty years to this great work and discovered 1,290 close stars, while Professor W. J. Hussey has discovered many and remeasured all those discovered by Russian astronomers.

Prominent among them are the stars Gamma Andromeda, as shown in cut 90. The maximum distance between the components was in 1877, 0.84 second. At this writing they are less than half a second, and scarcely visible as two points in the Lowe 16-inch telescope, if at all.

The two dots—large suns, however—of Gamma Andromeda, look like one in anything but a large telescope. And the larger the object-glass and the higher the power of the eye-piece the



Cut 93. Barnard's Milky Way.

wider is the black, infinite space between. This is called separating or magnifying power, but not a solitary star in the celestial vault can be magnified by any instrument men can make; their distances are so stupendous that they all look like minute points. What the telescope does is to bring millions more into view. Planets near home are all magnified into wide discs.

Of all telescopic binaries, perhaps sixty orbits have been computed with varying degrees of accuracy, measures being as diffi-

cult as any dealt with by astronomers. But binaries capable of detection by telescope are few indeed compared to the vast number now being discovered by that all-powerful and marvelous instrument, the tele-spectroscope.

Thus space contains countless suns, revolving around their centers of motions with great speed. Many millions of these may be surrounded by cool worlds, each inhabited by beings for more exalted in mental power than the human animalculæ.

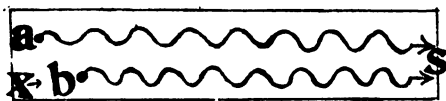
XXXIV.

z.

DISCOVERY OF SPECTROSCOPIC BINARIES.

"The universe is a unique, perfect and spherical production, since the sphere is the most perfect of figures; animated and endowed with reason, since that which is animated and endowed with reason is better than that which is not."—Timæus of Locris.

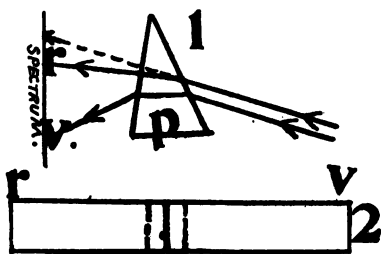
The binaries mentioned in XXXIII were all discovered by means of the telescope, measured with micrometer, and their masses computed by gravitational methods; that is, by Kepler's laws. But the detection of vast suns revolving around their mass centers in space at once awakened the keenest interest. These recondite researches were made with the spectrograph—a modified form of spectroscope attached to the greatest telescopes. Their discovery was made possible by an abstruse law of wave motion known as Doppler's principle, by which if a light source comes toward or recedes from the observer, its velocity can be found.



Cut 94. Doppler's Effect. A and B are luminous points, emitting waves in the direction S. While waves move from A to S, B moves from X to B.

Cleared in cut 94, where A is a source of light at rest. To its right are eight waves moving to S, while B also is a light source, and was formerly at X. Let both waves enter the slit of a spectroscope, S, at the same time. While light was moving from A to S the source of waves, B, moved from X to B, over

space equal to one wave-length. Then, since the velocity of light does not change, it is evident that the light waves will be crowded into the space properly occupied by seven normal undulations. That is, each will be one-eighth shorter. This is a bed-rock fact in nature, and leads to the most wonderful deductions. All along in this series it has been shown that the shorter the waves the greater is their refrangibility, or property of being bent aside out of their course by refraction of a prism or diffraction of a grating. Violet is bent the most and red the least, for violet vibrates nearly twice as fast as red, therefore its waves are slightly more than half as long as red. Whence the fact stands out that the place of a color, or if this is absorbed, a line, in the spectrum is determined solely by its wave-length.



Cut 95. White Light (Fig. 1)—Passing through a prism, P. Fig. 2 Resulting displacement spectrum shown in dotted lines.

This is cleared in cut 95, where white light is entering a prism as a band and emerging as a wide spectrum, the violet being deflected aside the most, in figure 1.

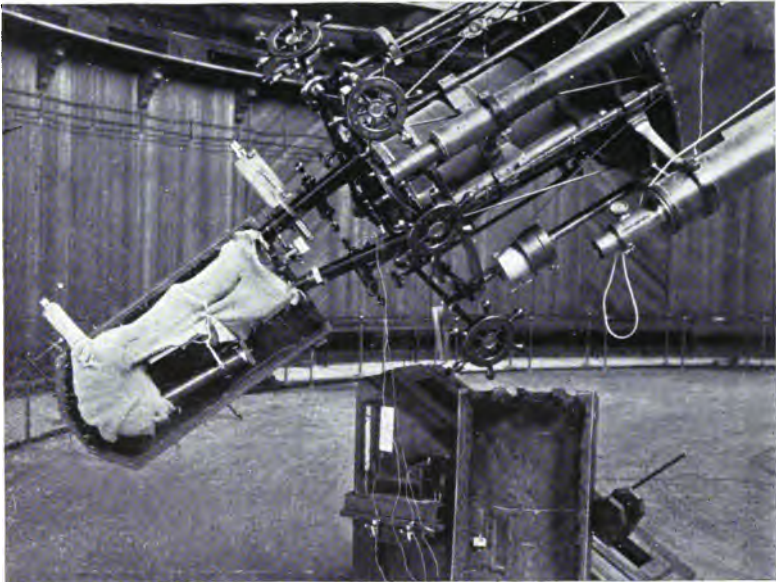
Basic Law: If a source of light is approaching, the lines in its spectrum are displaced toward the violet; if receding, the lines shift toward the red.

With breathless interest let the powerful spectroscope be turned full on the stars, and see what will appear!

Behold! The spectra of many stars actually show displace-

ment, now toward V, and then to R, as shown by the dotted lines in figure 2, cut 95.

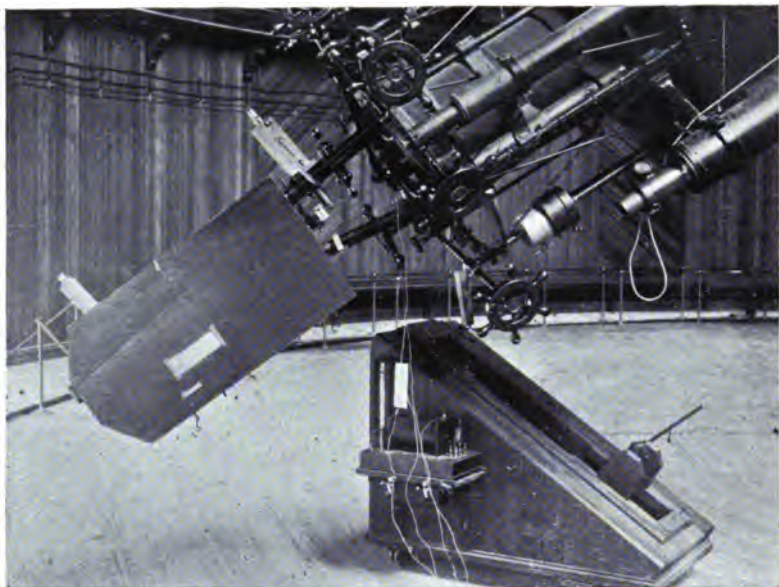
Human skill is taxed to the utmost in these delicate researches. The slit of the spectrograph is exceedingly minute, and the great driving clock moving the giant telescope must keep up with the rotation of the earth with extreme accuracy. The entire



Cut 96. The Mills' Spectrograph in the Lick Observatory—cover off.

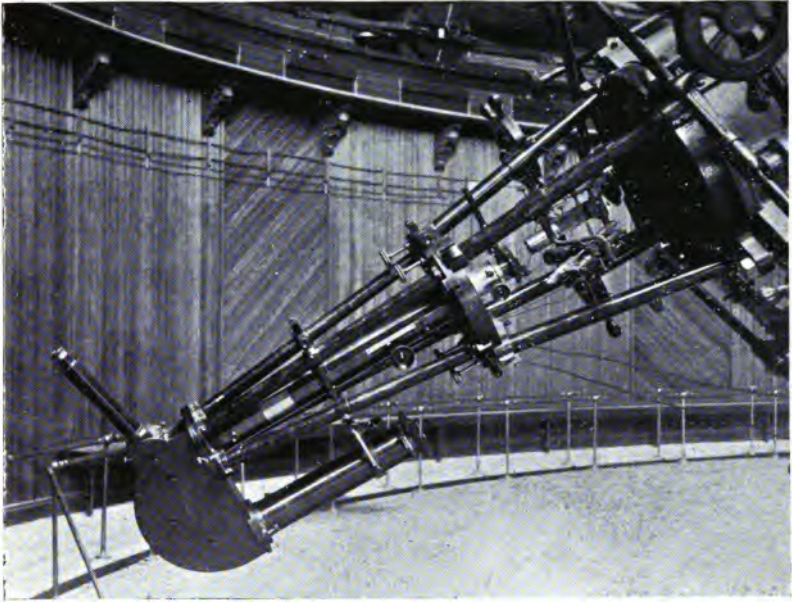
spectrograph must be kept at the same temperature throughout the long exposure of the sensitive plate. This is accomplished by inclosing the entire instrument in a non-conducting envelope and keeping the interior at a constant temperature by means of electric resistance coils.

All this is shown in cut 96, the now famous Mills spectrograph in the Lick Observatory.



Cut 96A. Mills' Spectrograph, enclosed in constant temperature case.

Professor W. W. Campbell, with this instrument, has wrested the most reluctant secrets from the universe and told the motion of suns, brought unknown binaries and distant systems of suns in revolution to the gaze of astonished man. The complex mechanism in the upper and right hand part of cut 96 is the end of the 36-inch equatorial. The spectrograph is inclosed in thick woolen cloth. The box is of cedar, and its cover is seen on the floor. The little tube is the guiding telescope to center the apparatus, and looks down on the train of prisms; while above is a window through which the micro-thermometer, sensitive to one-twenty-



Cut 96B. Mills' Spectrograph without case.

fifth degree, is read. The great object-glass—36-inch—far above, receives lights from suns, sends it through the tiny slit, one-thousandth of an inch wide, and prisms to the spectro-camera, where the wondrous graphs are secured, telegrams from suns so distant that the mighty void between cannot be measured.

Cut 96B is the Mills-graph before the case for regulating temperature was added.

There are other spectrographs in the world, notably that of Vogel, in Potsdam, Germany, but none have dragged forth mysteries more arcane than the Mills graph.

MOTION OF STARS IN THE LINE OF SIGHT.

Many suns are thus seen to be approaching, and as many receding with varying speeds, all rapid. The star must approach or recede on a straight line for motion to be detected, for side-wise motion cannot be seen in a spectroscope, since it does not change wave lengths.

Doppler's law can be proved by any one who will stand by a railway when an express is coming, if the bell or whistle sounds. If approaching, the key note rises, for more waves enter the ear, while after the train passes, the note falls.

Approaching.		Receding.	
Miles per second.		Miles per second.	
Alpha Arietis	12	Aldebaran	31
Gamma Leonis	25	Betelgeuse	18
Spica	11	Rigel	14
Altair	24	Capella	30
Polaris	12	Alpha Coronæ	20
61 Cygni	27	Regulus	—
Procyon	7	Eta Pegasi	3
Arcturus	5	XI Piscium	19
Beta Herculis.	30	Epsilon Hydræ	30
Sirius	5		

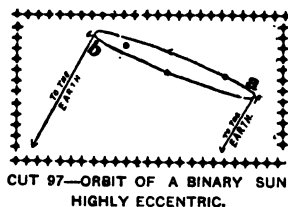
In cases of binaries moving in the line of sight the motions given are those of the center of mass, around which both revolve. Combining quite a number of cases, and taking their mean, it appears that the velocity potential to or from the earth is about 16 miles per second, the speed of the earth on its orbit being $18\frac{1}{2}$ miles per second. Below is a table giving periods of revolutions of binaries, discovered by means of the spectroscope, together with their orbital velocity in miles per second.

SPECTROSCOPIC BINARIES.

Names—	Periods. Days.	Orbital Velocities
		Miles per Second.
Mu Scorpii	1.45	144.0
Pi Scorpii	1.57	
Delta Orionis	1.91	44.5
Beta Persei	2.87	25.8
Castor (1)	2.91	7.0
A. G. C., 10,534.....	3.12	190.0
Beta Aurigæ	3.98	75.0
Pole Star	3.98	2.0
Spica	4.01	57.0
Delta Cephei.....	5.37	13.0
Eta Aquilæ	7.18	13.4
Zeta Centauri	8.02	
Zeta Geminorum	14.15	8.2
Iota Pegasi	10.20	30.0
Beta Lyræ	12.91	113.0
Xi Leonis	14.15	35.0
Lambda Andromeda	20.00	5.0
Capella	104.00	16.0
Beta Herculis.....	412.00	8.0
Chi Draconis	282.00	11.0
Eta Pegasi	818.00	9.0
Beta Capricorni	1,000.00	

This is a remarkable range in time and velocity, from 45 hours to three years, and from two to 190 miles per second. So vast is the distance of Polaris that an error is easily made in bringing out its speed only two miles.

Not one of these stars would ever have been known as binaries without the spectroscope, for no telescope could be made to see them double (they look like a point) with any magnifying power. And their spectra are all photographed, so that in the future, should changes occur, they will be seen.



DETECTION OF BINARIES.

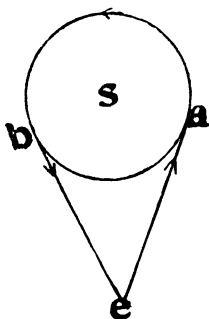
Call A and B two suns, so close that no telescope could separate them; but let them actually be revolving as shown in the orbit, cut 97. When the sun of less mass is at A it is receding from the earth, and approaching with greatly increased speed when it moves around in the direction of the arrows to B. The lines of sight to the earth are parallel as shown, no matter how large the orbit of any binary yet discovered may be. And waves on these lines enter the spectroscope on the dust particle called the earth, as at S, cut 94, and displacement is measured. And the velocity of approach or recession can be computed by mathematical formulas or determined by experiment.

VELOCITIES AND DISPLACEMENT.

In cut 98 let S be the sun and E the earth, while A and B represent the planet Venus at opposite points on its orbit. At A the planet is receding from the earth on a straight line, while at B it is approaching. But the velocities of Venus at these points

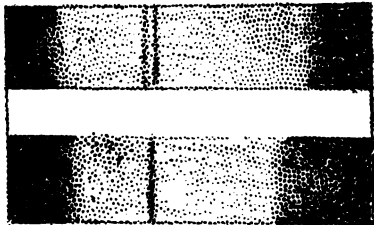
are known with great accuracy, so the value of displacement of spectral lines becomes known.

If an observer on an express train, at one mile per minute, travels toward the star Vega for 100,000,000 years, and takes a powerful telescope—the largest made—and a spectrograph, and should turn and look this way, straining his eyes, he would see a faint and struggling ray from our sun. With consummate skill he might secure a spectrogram showing displacement. If he did, he would find the shifting toward the violet, and computing would find the sun approaching with a velocity of twelve miles



Cut 98. The Sun, S; E, the Earth; A and B, Positions of the Planet Venus.

per second. For our little star—the sun—is moving toward the giant Vega, and drags along its stately company of planets, moons and comets. Our star is not a binary; it is solitary and alone in space. A ship in the center of the Pacific ocean is not more lonely. Indeed, not at all, for her crew can speak with human kind on any distant shore by space waves—soon. For some on land know that such a ship exists; but if the sidereal universe is filled with intelligent beings, only professional astronomers have heard of the sun, and none are aware that the earth is in existence.



Cut 99. Spectrum of Beta Aurigæ. Upper Figure showing Displacement of a Line.

In cut 99 is shown a marvelous spectrogram of the binary sun, Beta Aurigæ, where two suns make revolution in four days, with velocity of seventy-five miles per second. But what shall be said of Mu Scorpii, two suns rushing with a terrific speed of 144 miles per second, making circuit in forty-five hours?

XXXV.

SPECTROSCOPIC BINARIES.

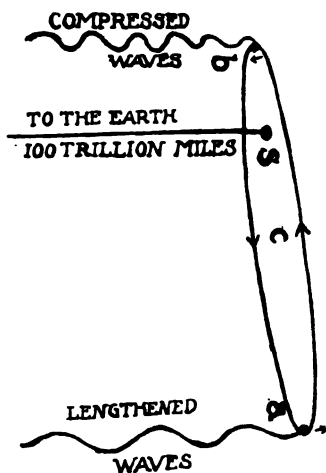
O Thou of whom all is the manifestation,
Thy nature is the spring of thy being:
Whatever is, is thou;
We are all billows in the ocean of thy being;
We are a small compass
Of thy manifested nature.

—From Dabistan, Vedantic Phil., Hindu.

Since the evolution of the human species began, or since spoken or written language developed, or since man began to think, since he first questioned nature, and through all of his devious and erratic career, whether within the historic period or before, all achievements wrought by his hands fall short of the marvelous work recorded in this chapter. This great achievement of the brain of man beyond comparison with anything else, startling even to the men who do the work, is the vast problem lately solved of finding the masses of suns without knowing their distance.

In chapter thirty-four, the quantity of matter in suns was computed by well-known laws of mechanics, for in every case the distances from the earth to these distant suns were given. But by spectroscopic researches on waves of light, fully explained under the title "Doppler Effect" a plan was discovered that borders—one would think—on the limit of human powers.

Cut 100 shows compressed and expanded waves from a binary sun. The eye of the reader should be imagined to be in the plane of the paper looking toward S. Cleared in cut 100, where S is a large sun with a smaller sun making regular revolutions around it on an orbit of great eccentricity. A line extends from S in the direction of the earth, which in the cut is marked distant 100 trillion miles. It could as well have been 200, since distance has nothing to do with the problem, pro-



Cut 100. Orbit of a Star around S. Waves that reach the earth are compressed and lengthened,

viding sufficient light can pass through the space, whatever it may be, to form a measurable spectrum. At A the revolving sun is retiring from the earth, and waves of light—since neither rates of vibration nor velocity of propagation change—must become longer, and a less number enter the spectroscope each second; and become shorter at B, and more pass into the slit. In Chapter thirty-four, cuts are given showing that this change in wave-

lengths produces lateral shift of lines, now toward the red, and then toward the violet, and speeds of approach and recession corresponding to lateral displacements are known, which knowledge leads to surprising results.

HOW TO WEIGH BOTH SUNS.

It will be understood that cut 100 is a spectroscopic binary, that is, the smaller sun whether at A or B cannot be seen in any telescope, both suns look like one, even in the 40-inch glass. Their real distance apart may be many million miles, yet so stupendous is the distance from the earth that they look like one. But the spectroscope deals with waves requiring 64,000 to make one inch, and can detect variations in velocity of the flying sun where the telescope alone would be powerless. Neither can the spectroscope see the revolving sun, whether at A or B, all that appears in any spectroscope is the band of colors called the spectrum. All that it does see in this case, is the change wrought in lengths of light waves at A and B. But this is enough to enable mathematicians to compute the quantity of matter in both. The curve around the large sun (S) is an ellipse, whose properties are known with rigid accuracy. B is the periastron, and A apastron, and velocities at each are measured. At A the speed is slow, while at B it is so enormous as to be past comprehension. But, with both velocities, it is possible to determine the average velocity all the way round. And by watching, the time of revolution can be ascertained.

A train moving 6 hours with a speed of 50 miles per hour travels 300 miles.

And a sun whether on an ellipse or circle, moving 50 years with a velocity of 40 miles per second, describes a distance determined by simple multiplication. Thus the great fact now appears.—

THE SIZE OF THE ORBIT IS KNOWN.

From Kepler's Law—see chapter XXXIII,—it is known how much matter is required acting by gravity, through any given distance, to impart any given velocity, to prevent the two suns from falling together. And thus human genius has found the masses of binary suns sunk in unfathomable depths, so deep that no micrometer can give any clue to the distance. Thus since man appeared, no instrument, no concept, no achievement, can compare with this mighty work.

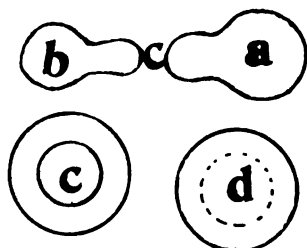
BETA LYRAE.

This massive binary presents phenomena of great interest to the spectro-physicist. Bright lines are seen in its spectrum, and dark lines at times are superposed either over them or closely side by side.

But the bright and black lines oscillate now to the right and now to the left—toward the red and to the violet. Most accurate photometers are now in use. They measure minute variations in the intensity of light of variable stars, and a majority of binaries sent out variable quantities of light. The 3.6 mg. star Beta Lyrae, near the bright star Vega—now glorious in its radiant splendor, rising early these June evenings in the northeast—is variable.

Watching closely, the light is seen to decrease to a minimum in six and one-half days, and then the intensity begins to rise; but by looking carefully with micro-photometer at the time of next minimum, it will be noticed that the light is not the same as in the first minimum. But maxima are equal. Here was a surprising case, unequal minima and equal maxima. Renewed observations were made by the ablest astronomers, and none could find the cause, until Professor G. W. Meyers came to the rescue.

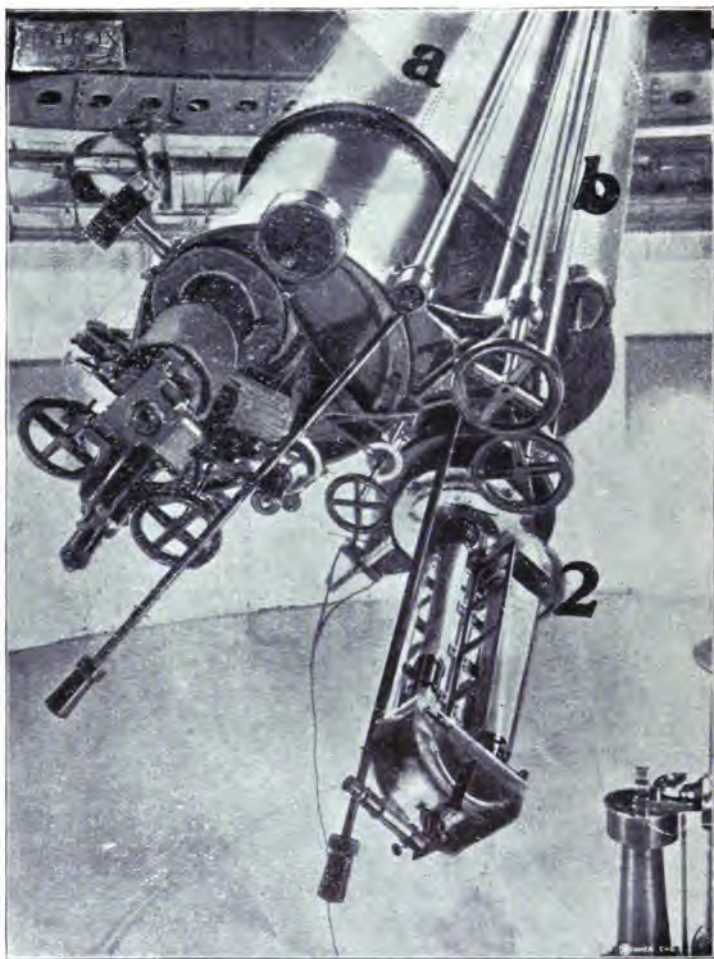
The remarkable system of Beta Lyræ is made clear by Meyers' demonstration in cut 101. Not being aware that Professor Myers has printed any cut, this one is drawn to represent the phenomena as described by him, using Poincare's apioid form of sun. The apioid will be explained in the next paper. In cut 101, a and b are two suns, distorted in shape by centrifugal tendency due to rapid revolution,—a complete circuit is made in 13 days,—



Cut 101. Meyer's Conception of the Evolution of the Binary, Beta Lyræ.

and by Darwin's tides. Let the small sun, b, approach the reader's eye, and a, recede, below the plane of the paper, both revolving around their center of mass, c. The side view as seen from the earth presents the maximum light, for both a and b are visible,—as one star, however,—their distance from the earth is so great as to forever preclude their ever being seen separated. But the spectroscope measures their radiant waves. As they turn, b will come between the observer's eye and a. The small sun is two and one-half times as bright as the large. The combined light of both stars will enter the spectroscope on the same straight line, and the result is the bright minimum, as shown at c in the two concentric circles below b.

When b revolves so as to be behind a, as shown in the dotted circle d, the light of a only will be seen, and the result is a dim minimum alternating every $6\frac{1}{2}$ days. If both suns are ellipsoids,



Cut 102. Dr. Vogel's Visual Telescope A and Photographic Telescope B and Spectrograph, 2. Potsdam, Germany.

—ovals—but of different sizes and brilliancy, results would be the same, as in the pear-shaped sun here given.

Period of revolution around mass center, 13 days.

Distance between centers of suns, 30,000,000 miles.

Mass of small sun, greater than our sun, 9 times.

Mass of large sun, greater than our sun, 18 times.

Density of both suns is less than that of air.

Velocity on orbit, 110 miles per second.

Distance from the earth unknown, and immeasurable!

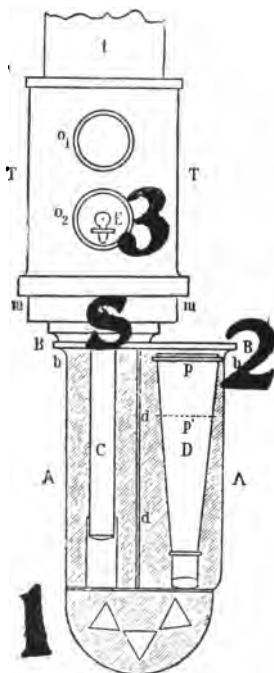
But the mass is known, and the chief work of human hands wrought—mass without distance.

The mystery is, how a sun of such low density can be hot enough to send light to such incredible distances as the earth. However, electricity may be in activity in this phase of matter. Such intricate problems are beset with chances for mistakes, for if errors of a few hundred-millionths of an inch are made in measuring displacements of lines, the result will be vitiated by corresponding errors.

The values here given for Beta Lyræ are those of Vogel, determined with his new spectrograph lately installed in Potsdam, as shown in cut 102. At A is shown the end of the great visual telescope, and B is the graphic telescope, for waves that affect the retina of the eye will not affect silver salts to make good graphs. So the objectives have different focal lengths. At 1 is shown the case inclosing the train of prisms. These analyze faint stellar light, separate the waves and form a displacement spectrum on the sensitive plate at 2, where it is graphed for measurement of its lines under a microscope.

Cut 103 is the interior of the spectrograph, showing three prisms at 1, and the plate at 2. At 3 is an opening in front of the slit S, where may be placed a Geissler hydrogen tube, flashed by electricity, so that its light can enter the slit with that from the star, for comparison. Since the lines are side by side, either from a reced-

ing or approaching star, with those from the incandescent hydrogen, lateral shift can be measured with accuracy by micrometer. Or, if iron or magnesium are prominent in the star, two terminals of these metals are attached to the poles of a high pressure



Cut 108. Interior of Dr. Vogel's Spectrograph.

induction coil, and are flashed, when the heat turns the ends of the metals to incandescent gas, which also sends vivid light into the slit for measurement alongside of the same metals white hot in the distant stars.

Dr. Vogel has already made many discoveries in the motion of stars in the line of sight.

POLARIS.

In 1899 Professor W. W. Campbell discovered the polar star to be a spectroscopic binary with a period of revolution of 3d. 23h. 15m. around the center of mass of itself and an invisible companion. But this center of gravity was found to be itself in motion with a variable velocity, therefore disturbed by a third and also invisible body. Thus two suns are revolving, and a dark world like the earth or Mars is making circuit around them. Hartman's recent researches indicate for the dark planet a period of fifteen years, and Campbell gives its speed as about two miles per second, at a distance from the center of gravity of the two suns of 300,000,000 miles. Computing, the combined mass appears to be closely one-sixth of our sun.

CAPELLA.

This magnificent sun was discovered to be a spectroscopic binary by Professor Campbell in 1899. Its periodic time of revolution is 104 days, with a speed of eighteen miles per second; while its mass, according to Professor Newcomb, is ten times greater than that of our sun. Thus a majestic and new branch of sidereal astronomy is being rapidly developed. New and improved methods of computing orbits are also in evolution, notably by H. N. Russel. And it seems likely to come out that parallaxes of stars will be determined with accuracy in the spectrograph that are so far away that the telescope alone will be forever unequal to the task.

Doubtless all the physically connected double stars are binaries, that is in revolution to prevent collapse and collision. Knowledge of the universe is now being immensely extended in the discovery of gigantic suns in rapid revolution with periods ranging from a few hours to many years.

XXXVI.

STELLAR EVOLUTION.

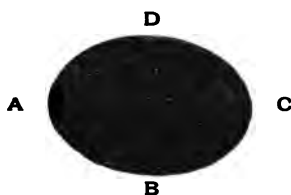
"The substance of the heavens and of the stars is called ether: not that it is composed of flame, as pretended by some who have not considered its nature, which is very different from that of fire, but it is so called because it has an eternal circular motion, being a divine and incorruptible element, altogether different from the other four."—Aristotle, "Letter to Alexander."

"Amongst the stars that are visible move others that are invisible, to which in consequence we are unable to give any names. These latter often fall to the earth and take fire like that star-stone which fell all on fire near Ægos Potamos."—Diogenes of Apollonius.

It fell to the lot of two men to change the current of human thought for all time. Charles Darwin established on immovable rock the sublime doctrine of evolution among living things. And his not less illustrious son, George H. Darwin, has for all coming ages rooted and grounded the profound doctrine of evolution in all inorganic matter, extending to the confines of the sidereal universe. The most profound and abstruse mathematics that has yet evolved in the human brain has been employed in these elaborate researches. This gave the earth's place—so now the evolution of all animate and inanimate things can be traced. The chief product of intellect, since man appeared, is primordial cosmical evolution.

The brain of George H. Darwin was the first to see that the surging of tides in ancient liquid or gaseous suns did

more work in the development of stellar systems than any other agency. As often happens, two minds on earth became impressed with a great truth at the same time. Dr. T. J. J. See saw this basic law very soon after Darwin, as an independent discovery, not knowing that Darwin had also seen the great light. The case was similar to that of Le Verrier and Adams, who both computed the mass of Neptune before the eye of man had looked upon it. For mathematics has clearer vision than the eye.



Cut 104. An Ellipsoid.

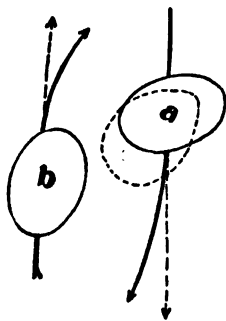
Cut 104 is an ellipsoid. Suppose a gaseous or liquid sun should assume this form, or any other ellipsoidal form by revolving around the long axis AC or the short, DB, then will the deviation from a sphere depend on its speed of rotation and internal viscosity. Thus the earth is an oblate ellipsoid revolving around its short axis DB. Since its ellipticity is slight, it must have been in its consistency, quite viscid when its crust was formed.

In cut 105 let two spheroidal suns a and b come within each other's neighborhood in their random flight in early stages of evolution—for all suns fly at random now.

Let these two plastic suns pass by forever, on the lines shown, then when at the nearest approach their gravity will act upon each other. But that attraction changes their entire subsequent career. Let one or both suns be in rotation on either axis with any velocity. Gravity of each will produce distortion on the mobile mass of the other; and draw it out of the regular geometrical form. But centrifugal tendency of rotation still acts

on the changed shape and produces most remarkable and far-reaching results. Each mass will leave its original path, no longer traverse the dotted lines, but make a graceful bow or nod to each and recede forever on a hyperbola for a track. But each sun will be broken into two suns. Let sun b evolute itself, and direct attention to a, where it is seen drawn into a new shape by the attractions of b, as shown in the dotted curve, or pear-shaped mass.

When Darwin and See were casting plumb lines over the



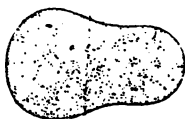
Cut 105. Plastic Suns passing, nearer to return.

sidereal structure, the French geometer, Poincare, sunk a sounding line into the fathomless sea of space. He found an equation calling for an entirely new geometrical form totally unknown to mathematicians, and of course not known to La Place when he formulated his famous and now superseded hypothesis of the formation of worlds by the abandonment of peripheral rings by rotating and subsiding gaseous or liquid masses.

Cut 106 is Poincare's all-important apioid, through which form many binary suns are now known to be passing. The apioid is based on rigorous mathematical formulas, which he elaborated.

LAW: Where there is a mathematical, there is also a physical possibility.

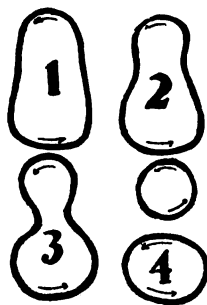
Could the brain of that great mathematician, La Place, now become reanimate, its genius would doubtless at once give up mainly the ring doctrine of stellar evolution. It is possible that a nebula may break up into rings by action of other masses and its own tenuity and internal state, but that is not the leading fact in nature.



Cut 106. Poincare's Apoid.

GEMMATION.

Here is encountered a mighty law that seemingly holds the whole of nature in its grasp, reaching from a minute living amœba to white-hot sun. In cut 107 is shown the process of gemmation of an apoid sun to form two. Figure 1 is the regular



Cut 107. An Apoid Sun dividing into two.

geometric apoid rotating in the direction of the arrows. In figure 2 contraction is more pronounced, while in figure 3 the segmentation is well advanced, and the wondrous work is complete in 4, when two suns are formed, both rotating in the same direction of the original cosmical mass. Each sun may be gaseous or liquid

and from one million to a thousand million miles in diameter, according to their constitution, whether liquid or gas. This is a phase of evolution of inanimate matter. But all living matter makes identical evolution.



Cut 108. An Amoeba making Segmentation.

Cut 108 is that of one amoeba making reproduction by gemmation, and all animals, from amoeba through all protozoans, radiates, mollusks, articulates and vertebrates to man, are simply congeries of cells.



Cut 109. The Sun V Puppis in Process of Gemmation.
The ligament is about to be severed.

The binary sun named V Puppis, from a discussion of all observations by A. W. Roberts, will satisfy equations based on spectroscopic determinations, by the mathematical figure in cut 109, where light still lingers in the band not yet torn asunder in the forming suns. These giant suns make revolution in one day ten hours and fifty-four minutes, and their density is only one-fifth that of our sun.

XXXVII.

EVOLUTION WROUGHT BY TIDES.

"The lovely Dawn, arousing man, goes before the sun preparing practicable paths, riding in a spacious chariot; expanding everywhere she diffuses light at the commencement of the day."

"Harnessing the purple oxen to her car, unwearied she renders riches perpetual; a goddess praised of many, and cherished by all, she shines manifesting paths that lead to good."—Rig Veda Sanhita, Vol. III, p. 369.

The computation of the action of primeval tides on forming worlds and suns involved a grade of mathematics much more complex than the formulas employed in the discovery of the location and mass of Neptune before the eye of man had seen it. George H. Darwin first gave tidal formulas to the scientific world and aroused the supreme admiration of all who heard the wondrous story.

PRIMEVAL TIDES.

Darwin's mathematics looked on primeval chaos, where lens and plate are useless. He began his history of evolution with the ancient earth and its moon, but the reasoning applies to the development of binary suns as well. Tides began the next day after the moon separated by gemmation from the equator of the earth; neither had time to assume the spherical form before tidal force clutched both. Tides formed the earth and moon.

FIRST DAY.

The first day began at the instant the umbilical cord leading from the viscous earth to her daughter the moon was severed, and ended when the point of rupture came round to the same place again. The first month began at the instant of the moon's birth and ended when it also came to the same point after one circuit around the primitive earth. Both day and month have from that time been in constant change in length; they are both changing now—no two of either being precisely of the same duration. The first day and first month were very nearly equal, and the length of each somewhere between three and five hours. Not exactly equal, for then there would not have been tidal friction—the worker that made both day and month—for the same face of the moon would have forever been turned toward the earth and the same point on the earth toward the moon. There would have been one high tide on the earth under the moon, and on the moon opposite, but no friction, so both worlds would be held by gravity, as if joined by a rigid rod of steel, and hence no friction, and both month and day would have remained between the mathematical limits of three and five hours. The difference, no matter how slight, between the early months and early days was no doubt caused by the disturbance of rupture, but if any variation whatever occurred, then tidal friction formed the earth-moon system as it now exists.

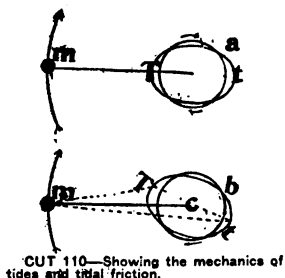
FRICTION DUE TO TIDES.

A tide in water is known to have friction within its mass. A tide in oil, tar, honey, liquid steel or melted rocks would cause far more internal friction than tides in water, alcohol or gasoline. The action of tidal friction is as universal as the law of gravity, heat or electricity, and its discovery and mathematical development takes rank with the discovery of gravity and its Newtonian law. The reader is referred to XXXVI for cuts showing the ancient apioidal earth and the separation of the moon mass.

HOW TIDES PLACED THE MOON ON ITS PRESENT ORBIT.

The mechanics of tides and tidal friction may be seen in cut 110, adapted to the purposes of this note from both Dr. See and Professor G. H. Darwin, omitting all technical and mathematical portions.

Figure a shows a circle and an ellipse, or a sphere and an ellipsoid. The sphere represents the form of the earth if sunk in space far away from any attracting body; really the earth has never been a true sphere. The ellipsoid represents the shape of the semi-liquid or plastic earth, with tides at T and t, caused by



CUT 110—Showing the mechanics of tides and tidal friction.

the moon at m. If the day and month had been at that time equal in length, the tides would always have remained as at T and t on a straight line with the centers of the earth and moon, until it cooled and a solid crust formed, so the earth would now be an ellipsoid. If the day and month were of unequal length, and the substance of the earth absolutely without friction, then the centers of the earth and tides would have been on the same right line; but this is impossible, for even hydrogen has friction within.

EFFECT OF FRICTION.

But the early days were shorter than the month, and the viscosity of the earth's mass had more friction than a water world. The effect was most important and is now known to be at least one riddle of the universe.

Let figure a represent noon of the first day, or morning, or evening, and figure b the same time on the next day. But the day was shorter than the month—that is, the earth rotated on its axis faster than the moon revolved in its orbit. This would have no effect in the absence of internal friction, but friction was present, the tide wave was retarded, could not keep straight below the moon, so the more rapid earth carried it by the line joining the centers of the earth and moon, as shown by cut 110, figure b, where the dotted line T, t, is the axis of the tide next day, and has been from that archaic time and must ever be until the earth becomes throughout more rigid than steel, and the oceans solid ice. In figure b the moon is around to m again at the end of the month, but tide T is always in advance of the place it would have been had friction failed, and is now.

MECHANICS OF TIDES. ACTION EQUAL TO REACTION.

Tide T is nearer the moon than t, hence the attraction of the moon on T is stronger than on t. The pull of the moon on the gravity rope on T tends to pull back T, to bring the dotted line T-t into its original line m-c, while the weaker attraction, m-t, tends to counteract it and make the earth turn faster, but m-T is the strongest and must prevail. So the earth is actually slowing down its rotary speed now, the day is growing longer, and even during all that time since the first day.

The mass in tide T reacts and pulls on the moon and tends all the time to make it go faster on its orbit in the direction of the arrows. The pull t-m tends to retard the moon, but T-m is more potent, it acts with greater intensity on the moon and tends to increase its speed and, therefore, make the month shorter. One on first reading would think, of course, that the month was in these early times growing shorter, but such evidently was not the case, for it is twenty-seven and one-third days long now, and less than five hours in length then.

The instant the moon is accelerated a mighty reaction —centrifugal tendency—lays hold upon it. This terrific power is not an inherent property of matter, but merely a reaction against original inertia common to matter in every form.

Tie a cord to a stone, whirl it around, the string pulls; double the velocity and the pull increases four times, that is, this reaction is enormous—it varies as the square of the velocity, as observed in bursting grindstones. A solid wheel of steel will fly to pieces if turned fast enough.

As soon therefore as the chaotic moon was accelerated centrifugal tendency threw it away farther from the earth into a longer orbit. It required more time to make a revolution. Thus, incredible as it may seem, tidal friction pushed the moon away from the earth and made the month longer. The united chaotic earth and moon revolved on an axis before the moon made escape by segmentation, so the term “first day” above means the first time the earth made one rotation separate from the moon. Had it not rotated before, then a furrow or fissure would not have formed owing to absence of centrifugal tendency in the apiodal mass. Not only the past of the earth and moon can be traced, but the future. The revelations made by Darwin are more astounding than any ever presented.



GEORGE H. DARWIN

XXXVIII.

EVOLUTION OF THE EARTH AND MOON.

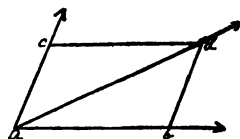
The sun remains immovable, and the earth moves round it in a circular curve, of which that star is a center.—Aristarchus of Samos.

THE FIRST MONTH.

Given a difference between the length of the first day and first month, however slight, even to a minute fraction of a second, then the present state of the earth and moon was inevitable. The entire mechanical work has been wrought by mutual tides. The agency—heat—has been escaping since, and the less the heat in both earth and moon the thicker the consistency of both masses, the lower the tides in both on account of increased friction, and the less the distance the moon must recede before it turns and begins its long period of winding on a spiral back to the earth. This question of how tides forced the moon away from the earth must be understood, for it is a fundamental law in nature. Tidal friction has done more work than all other agencies combined in the formation of planetary systems—where worlds revolve around suns. It is the giant now at work building up binary, ternary and multiple suns, at present seen in active evolution in every direction in space. In fact, it is the great worker of the universe, being the only method by which the primal power, gravity, can get worlds in its clutch to hurl them upon orbits. It separates

matter in the shape of crude chaotic masses, so the heat of the central mass shall not be too intense to destroy life on later revolving planets. Tides made our earth and moon. Friction due to tides completely accounts for the evolution of the sidereal universe. The vast subject must be understood by all who wish to know about the immense cosmical structure so overwhelming in its majesty and splendor. A book is required to treat this great new deduction of the human mind; so only elementary principles will be presumed upon here, not even daring to go near where Darwin is but once, and that to touch the "hem of his garment."

This is the absolute beginning of evolution of moons in place around planets, planets and moons around suns, suns and planets around other suns, and underlies the substructure of all stellar systems. If acceleration is understood the outlines of that stupendous machine, the universe, will be seen emerging from the most archaic obscurity like the coming of a ship from the mists of the sea.

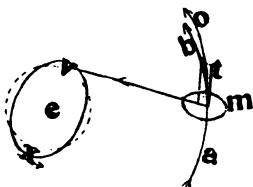


CUT 112.
Composition of two forces into one.
The forces *ac* and *ab* are united into *ad*,
all moving in direction of the arrows.

ACCELERATION.

The mystery of acceleration is cleared in cut 112, which shows first, the basic law of mechanics, the composition of forces. Let a mass be at *a*, and at rest. Let a force act upon it in the direction *a, c*, with an impulse able to cause it to move from *a* to *c* in one second. At precisely the same instant let another force act upon *a* with an intensity able to send it to *b* in two seconds. It will not move either to *c* or *b*, but will arrive at *d*.

The path a, d is always the diagonal of a parallelogram, if the forces are unequal; of a square if equal. Any number of simultaneous forces can be compounded into one. This law had to do with the evolution of all solar systems. The composition of forces—gravity and friction—on the primordial moon, reveals the hidden mystery why it left the earth.



Cut 113. Tides separating the Earth and Moon.

In cut 113, e is the ancient viscid earth, and m the chaotic moon, both in the grasp of gravity and in the clutch of tides. In cut 110, chapter XXXVII, the moon is shown acting on the earth, and in cut 113 the earth is acting on the moon; they shall be compared. In cut 113 e is the ellipsoidal earth drawn away from the dotted circle by the moon. The tide at v accelerates the moon on its orbit ab towards b. If, when the moon arrived at m, the earth were suddenly annihilated the moon would move on the tangent to its orbit, t. If the mass of the earth as suddenly increased, the moon would move toward v. If no change occurs, the moon will keep on its orbit to b. But the heaping up of matter at v has somewhat the effect of increasing the quantity of matter in the earth, because it brings some of it nearer to the moon and thrusts other portions away, as at x, that of v pulling with greater force on the line v m than if v were sunk within the dotted circle below. But at the instant the speed of the moon is increased, the mighty centrifugal tendency asserts its sway and hurls it off the orbit ab and sets the moon upon its new track ao, farther away from the earth. And this is why the moon

is 240,000 miles away from the earth instead of almost in contact, and why the length of the month is 27 1-3 days instead of scarcely more than one. The only reason why high tides developed at *v* and *x*, was because of friction in the viscous earth; for without friction tide *v* would have been exactly under the moon, and tide *x* opposite, the day and month being always equal and the surfaces of the moon and earth almost coinciding.

At the end of the first month, if it was any longer than the first day by any time whatever, and if the earth's mass had friction by any amount however minute, then the present earth and moon, and the present day and month were inevitable. For at the end of the first month the moon is again at *m*, but still farther from the earth and will traverse an orbit slightly outside of *ao*, and so on for each month, perpetually expanding its orbit like unwinding a closely wound coil or flat disc of tape. It will continue to unwind so long as tides exist, either on the surface or within the earth, the longest month being when the last tide on earth shall die away into rigidity. It will be noticed that at the moon's orbit each new path described at the beginning of every new month is the diagonal of a new parallelogram, as in cuts 112 and 113.

FUTURE OF THE EARTH AND MOON.

It is shown in the history of tidal evolution that if the first month had been shorter than the first day, the moon must have fallen back on the earth after the rupture of the ligament, if, indeed, such disruption could have taken place by the action of the earth and moon without the aid of the tides caused by the sun. However, the first month was longer than the first day, else the earth would not have a moon now. These results must follow: The length of the first day and month was somewhere between three and five hours; mathematics could compute the true time if accurate data could be had in chaotic states of the earth-moon. But it is a stupendous achievement to know that it falls within set limits. If either three, four or five hours, the truth of the doc-

trine of tidal evolution is not effected. The month is now 27 1-3 times longer than the day. But friction of tides has increased, is now increasing, and will continue to lengthen both day and month until they become equal, at which time each will be fifty-five of our present days in length. It will take the earth fifty-five times longer to make one turn on its axis than now, and the moon very nearly twice as long to make one circuit around the earth than at present. They will then be as firmly fixed in relation to each other as though joined to the ends of a bar of steel. If, when so clutched as in the jaws of a mighty vise, the moon is central over the United States there it will remain. The moon is clutched by the earth now, and always presents the same face this way. It is only a question of time when the earth will obey the moon's gravity and turn the same face to it. They will still revolve around their center of mass, as may be seen by attaching two unequal balls to a rod, suspending by a cord at their gravity center and turning. The earth and moon will still revolve around the sun, and the earth will have 27½ times longer day than now and night also, if the sun is shining then, if not, one perpetual night with moon invisible. But in all probability the sun will be dead. Thus when lunar evolution began the day and month differed, necessarily, by only a fraction of a second, and when evolution ends the day and month will again be equal—the first day being between three and five hours long and the last 1,320 hours (fifty-five days). The greatest number of days in a month was twenty-nine, and, as there are now 27 1-3, evolution is slightly more than half through with its career. Therefore, the least number of days in a month, the first and last, is one; the greatest twenty-nine. Matters are different on our neighbor Mars, for its satellite Phobos counts off more than three months every day of Mars; rises in the west, passes through all its phases in plain view of the Martians, each phase being less than two hours in duration. The sum and substance of the evolution of moon and planet from primitive

apioidal shape is that the first month of the detached moon shall be, any time whatever, longer than the first day. The same is true of binary suns. For if the month is longer than the day all parts of the earth pass in review before the moon, if not there would be no tides. And tides would be useless in absence of internal friction. So the cause of evolution of moons and planets and of binary suns is

TIDAL FRICTION.

Darwin's rigid analysis surely points to the fact that the final state of the earth and moon will be one of stable equilibrium. No fact in nature is better authenticated. The first state was unstable, else the earth would not have a satellite now. The sole cause of unstability was friction in tides. In the terminal state there will be no tides, for the earth will be as solid as the moon is at present. The earth and moon will be in deadlock and escape impossible. The term "last day" above is the day on which the sun sends its last wave of light to the earth and moon. Both will still revolve around their center of gravity in a period now called fifty-five days, in night that knows no dawn. Long before this all life will vanish from earth, but if Byron's last man could be on the equator, his only method of finding if the earth turned would be to watch the stars—younger than our star—the sun. To him the moon would be unknown as well as the sun.

The revolution will continue, the earth and moon still casting lifeless periods of time into past duration, while both will revolve on melancholy pathways around a frigid sun, recording useless times called years. Matter in which life is able to exist separates with exceeding ease and terminates the fleeting pulsation. The seething unrest, the heat, the clashing, kneading and rushing turbulence of the gigantic masses of suns and worlds in the midst of evolution must be hushed for a few moments into almost absolute quiescence and repose that life might appear and vanish. Thus life is a mere episode in the process of evolution of nature.

XXXIX.

EVOLUTION NOW IN ACTIVITY.

"That which is one the wise call many ways. They call it Indra, Mitra, Varuna, Agni, the winged heavenly Garutmat."—Rig Veda I, 164, 46.

Stellar evolution has by no means ceased, it is in an active state now, and can be watched by means of the telespectroscope in all directions in space. Gemmation of one sun into two, allows tides to set in and furnish suns and worlds with moons. At the instant of separation of two worlds, tides must act and build both into suns. Gravity is inherent in all matter, but cannot build a universe unless it exerts its power by the leverage of tides and these cannot build without friction. Since friction is also inherent, gravity and tidal friction formed and fashioned all that portion of the sidereal edifice within range of the best telespectro-cameras, for these write the history of cosmic evolution hour by hour. Cosmical life and death seem to be equal. Suns ending evolution, so far as can be learned at present, are comparable in number to those entering their long career. The quantity of matter now stored in dead worlds is greater than that in the hot and living.

The waste products, as far as science in its present condition is able to see, are heat and a minute trace of energy called light. Both are episodes and momentary while gravity is as eternal as matter. Heat, light and life are ephemeral, while matter and gravity are constant. All else in the universe at present known to men is variable. Gravity is the builder and has wrought in the

past and is now acting through friction. Centrifugal tendency is a reaction merely against gravity. Gemmation prepares the way for its instant successors, gravity and its opposing entity. These two, and time, formed all worlds. Thus activity is derived from gravity.

Matter and gravity existed before the universe assumed its present structural form, while astronomy and cosmical physics both teach that they will exist if it ends. If the fashioned structure does not end, that is, revert to chaos, then evolution is eternal. It has, however, been decided by psychologists, that the word eternal is powerless to make impress on the human mind, so vagaries about duration must give way to what is known.

MOTIONS OF THE STARS.

The words "fixed stars" have now disappeared from the literature of modern astrophysics. It is known that every star is in rapid motion. They move in every possible direction and the fact stands out that they move at random like bees in a swarm. It is almost impossible that any should move on straight lines. A right line is almost unknown in nature. The distances between suns are so enormous, that gravity is weak from sun to sun, so the curvature of solar orbits is slight. If the stellar structure is finite, it has a center of mass, and all suns and worlds whether alive or dead, must obey its attraction in a measure; yet a hundred suns in the vicinity of our sun might temporarily attract it more, than the immensely distant gravity center of all the suns. Since whether the universe is finite or infinite is unknowable, the center of universal attraction may be ignored, and attention paid to adjacent suns. Since they all move, the effect on every other is variable, so every sun in existence moves with varying velocity on a curve which is perpetually changing its curvature and direction.

Cut 114 represents a finite portion cut out of an infinite system of stars, with motions in every direction.



Cut 114. Any number of Suns cut out of any space.
They move in every direction.

Cut 115 represents the observed and measured movements of the stars in the Great Dipper in the constellation Ursæ Major, where five stars are seen moving in the same direction, all presumably condensed from the same nebula, while one of the pointers and one in the handle are in motion in other directions. These motions were measured by micrometer, but the spectro-



Cut 115. Drift of Stars in the Great Dipper.

scope shows that the five stars are in rapid motion away from the earth, while the pointer (A) is approaching and the star (E) receding with a speed different from that of the five common stars.

All but eight of the stars of that well-known group, the Pleiades (cut 116), move in one direction, so all these glittering stars are supposed to have been condensed from one mass of gas. It is also known that our sun is moving with great velocity through lonesome space, dragging its worlds along with perfect

order. Thus binary, ternary and multiple suns, as well as single stars like ours, and also groups, all have their own motions; binaries, of course, and related groups having the same direction, in relation to each other, but every conceivable direction in relation



Cut 116. Drift of Pleiades.

to space and all the other stars. So there are no fixed or motionless suns in space. Indeed, there could not be bodies at rest in free space dominated by the ruler of all—Gravity.

XL.

WIDE DIFFUSION OF MATTER.

"Nature, beginning of ages, is parent of all."—Diodorus 1-27. Apuleius, *Metamorphoses*.

The writer has seen incandescent hydrogen glowing in the stars Vega and Sirius. Sirius sets when Vega rises, therefore they are in opposite directions from the earth. The distance between these two giant suns is 256 trillion miles, and they are in our immediate neighborhood, for other stars known to contain hydrogen are as much as one hundred times farther apart. The mighty question at once arises, how came hydrogen so widely distributed in interminable space? It is omnipresent, and seems to enter the most archaic nebulæ and thence condense into suns. But it is too dense to fill all that portion of space now known to be occupied by suns and cool worlds. Iron is conspicuous and also magnesium, together with helium, in the most primitive type of suns.

When suns become older and more complex other modes are seen in the spectroscope. The only possible explanation of the fact that iron and hydrogen are seen glowing in suns in every direction, whose distance apart are many quadrillion miles, is that all matter now stored in suns and worlds was once separated into an exceedingly rare gas, or rather ultra gaseous form. For any gas known to chemists here, under terrestrial conditions, is many

hundred million times too dense to be compared with the probable diffusion of primordial matter. Helium and hydrogen particles would be miles apart if all matter now existing in suns appearing on late graphic plates should be uniformly distributed. And these are the rarest modes known. But the discovery of J. J. Thomson of corpuscles that have only one-thousandth of the mass of the hydrogen particle throws much light on the primeval chaotic mass, whence all suns and worlds were developed by processes of evolution, now observed in activity in every direction in space. These corpuscles have awakened the interest of every physicist in the world, and they are either electricity itself or its immediate carriers. A great fact seems to be prefigured—the universe is based in electricity, for electricity, no doubt, is a mode of matter.

At all events, speculate as one will, it is certain that if all matter now condensed into suns visible in the most powerful tele-camera were expanded into the same space now occupied by them, then space would not be filled, for even these corpuscles would be separated by distances very large compared to their diameters.

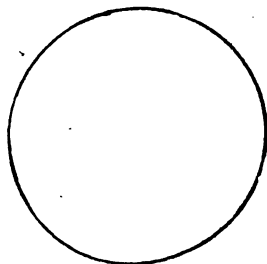
Let all that part of space at present occupied by suns and worlds in every possible phase of evolution be occupied by matter dissipated into an excessively rare condition, so rare that the Thomsonian corpuscles were inches or even feet apart—then the development of the original mass into a universe such as now exists was sure to follow from known physical laws.

EVOLUTION OF SUNS.

In cut 117, let the circle cut out space in diameter the distance traversed by light, moving with a speed of 186,000 miles per second during 30,000 years. This is not extravagant, for Sir Robert Ball, Astronomer Royal, estimates that the faintest stars of the seventeenth magnitude are so distant that 18,000 years are required

for light to reach the earth, making the diameter of the cosmic structure visible to man 36,000 light years. To be within bounds, 30,000 years is the period selected for computation in this note. The circle is drawn merely to attract the eye, and has no other use.

Kelvin has shown that the number of particles of any gas in one cubic inch cannot exceed six sextillion. The size of Thomson's corpuscles is unknown, their mass only being determined, which is the one-thousandth that of the hydrogen particle. Doubtless, however, their diameter is in some equivalent ratio, so the



Cut 117. Cosmical Sphere of Suns, 30,000 light years in diameter.

number above becomes one thousand times greater, or six septillion. In the appalling space selected, each corpuscle had plenty of room. The temperature was absolute zero—273 degrees C, and solid hydrogen and air would be warm in comparison.

Absolute rest at first obtained, when the sole ruler of matter—gravity—asserted sway, and motion began. If two corpuscles united, that was the beginning of a nebula, of which many thousands are now seen in all parts of the sidereal structure in every conceivable shape, faint wisps and filmy forms of original gas born of condensation from primordial corpuscular matter.

After inconceivable eons passed away, the appearance of things within the circle, so far as science can at present find, was

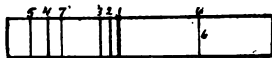
like that in cut 118, where nebulae have formed in all parts of the sphere, starting from minute corpuscular nuclei. It is the destiny of every nebula to condense into suns, for the process can now be seen and photographed on every clear night. These countless nebulae are at present seen on the plates in every possible phase of evolution from the faintest and most diffused mass of rare gas



Cut 118. Nebulae and Suns in evolution.

up to the final or solar stage. In cut 118, amœba form nebulae are shown; and also those in the shape of spirals, for Keeler's graphs revealed many to have the spiral form. Probably these were in rotation.

All nebulae so far subjected to spectrum analysis show hydrogen, others present helium, and many have lines emanating from a mode of matter not yet detected on the earth, provisionally named *nebulium*.



Cut 119. Spectrum of a bright Nebula. Lines 3, 4 and 5 are due to hydrogen and C is from helium. Lines 1, 2 and 7 are from an unknown mode, but called *nebulium*; 5 and 7 are faint and invisible in dim nebulae.

Cut 119 is the spectrum of nebulae, only the brightest being able, in a powerful spectrograph, to show all of the seven lines.

The line 6 is due to helium, which was unknown for a long time, always being seen in the sun as well as in nebulae. It was discovered by Ramsay on the earth in 1895, and isolated, when its line was found to coincide with the line in both sun and nebulae. Thus helium and hydrogen hover round about the beginning of evolution of the universe.

Astronomy and astrophysics, in their present state, are unable to see any other possible method of sidereal evolution than that here given. For, if all existing suns were evolved in the vicinity of the center of the circle, the problem comes up—how did they become dispersed to such incredible and inconceivable distances in which they are now seen? Separation, due to Darwin's tides, seems to be impossible, for gravity becomes very weak at these enormous distances.

In fact, the standing mystery of all astronomy is space. Why should suns now be separated by such unfathomable space? Why should our nearest neighbor be 25 trillion miles away? For it can be shown that if Alpha Centauri were only one trillion miles distant our planetary system would not be perturbed by any measurable quantity.

Evolution extends from corpuscle to dead suns and frigid worlds. In the turbulence and turmoil heat was the first mode of radiance to appear, then light; moisture came, and then life.

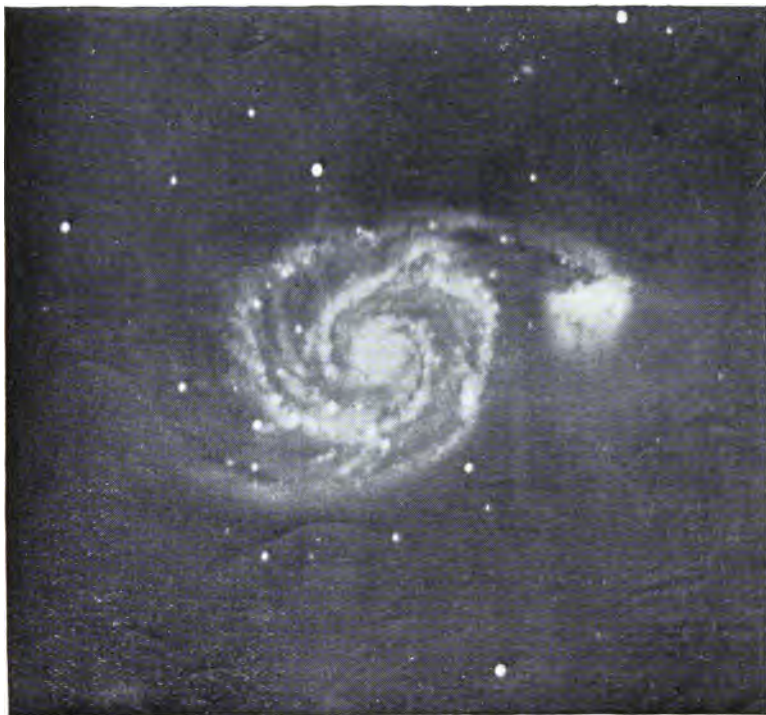
But life is of exceedingly short duration. The evanescent, fleeting, unstable and feeble thing or entity—life—was the last to appear in the midst of the stupendous cosmic war of matter and energy, and will be the first to vanish. A few degrees change in temperature either way will end it all. Short as may be the duration of organic life, that of its chief product—mind—is shorter still. For life existed ages on the earth before its last refinement, coherent thought, was evolved. Thus mind has the least duration of any entity whatever, for soon mentality will vanish, unconsciousness set in and oblivion succeed.

It can be shown that if the sidereal structure is in rotation about an axis, the centrifugal tendency is unable to project out-lying suns to their present distance, so the conclusion is inevitable that all space now occupied by suns must have been filled with material whence they were made by gravity and tides. If so, then the tenuity of the mass was so great as to reach the ultimate or final corpuscular state.

If, as seems probable in the present state of ignorance, corpuscles are electricity, then electricity is the first and last refinement of matter, for the indications of astrophysics are that the sidereal structure must be resolved back to the corpuscular state again to recondense into another. This mutation is necessary to regain heat, which at present is being lost at a frightful rate.

And modern science here has arrived at the same conclusion reached by our primeval Aryan ancestors at the base of the Hindu Kuh, in Northern India, many thousand years ago. For that recondite Hindu philosophical poem, the "Bhagavad Gita," says: "Matter is invisible in its primordial state, visible in its intermediate, and invisible in its final state." The latest science has nothing better to offer. Helium and hydrogen are the perpetual enigma. Why should the first matter to send out light be these? And how is it that iron appears so early upon the cosmic scene of upheaval, unrest and activity, or why should matter assume the eighty phases now known? Or what is matter? Perhaps these old questions never will be solved by man, yet the astounding discoveries of the last two years appear to indicate that they may not be beyond human powers.

Cut 120 is that of the great spiral nebula in Canes Venatici. Several suns are shown that have been condensed from the vast mass of gas. To the right, a large body of gas is separating by the gemmation process, while the whole presents the outlines of a gigantic spiral. Thus the history of cosmical evolution has been given as far as science can see at present. Whether the entire



Cut 120. Spiral Nebula. Canes Venatici.

congeries of suns and worlds revert back to the corpuscular state at the same time, or whether, while some are dissolving to chaos, others far away are just emerging from it, are questions at present insoluble. The new sun in Perseus last year was seen to resolve into a chaotic nebula. Mystery deepens, while men pale and faint in presence of these mighty problems.

XLI.

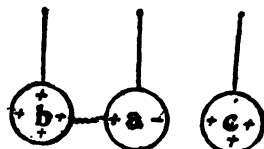
PRIMORDIAL ELECTRICAL INDUCTION.

"Thou art the arts and sciences, thou moral and political wisdom. The worlds have been preserved and reanimated by thee."—Indra's Praise of Lakshma. From Vishnu Purana I, Ch. ix.

Induction is a deep-seated fact in nature. In this paper electrical induction will be employed in striving to account for the archaic mystery of rotation. Very many theories have been advanced to account for the rotation of primitive nebulae, as well as spherical gaseous suns, and liquid, round about axes. How did rotary motion begin, and what mode of energy caused these vast masses to turn? In cut 118, Paper XL, the primal gaseous sphere is seen broken into great numbers of nebulae, and some are represented as having passed their successive steps of evolution up to complete suns. But all worlds in our solar system, as well as the central sun, are in rapid rotation on axes. And from phenomena of variable stars it is inferred that all suns, planets and satellites are turning.

The writer believes that this universal motion of rotation was caused by electrical induction. The phenomena of inductance ought to be understood by all, for nearly all electrical machines, now rapidly coming to the front as the workers of the world, are based on the fact that electricity acts at a distance and induces other mechanism to do work.

This is cleared in cut 121, where A, B and C are spheres—those so often used by the writer before students—being wooden croquet balls covered with a coating of lead or tinfoil. The balls were all suspended by a silk, or non-conducting, thread to the ceiling of the laboratory. The ball A is to be charged by the induction of C. The sphere C is to be provided with a charge of electricity from an electrophorus, Helmholtz, Atkinson, or any static machine, in another part of the room, and carried to its position of suspension. Suppose the coating is charged positively as shown. It instantly, by induction, separates the natural electricity, with which all known matter is endowed in the sphere A,



CUT 121—Charging the sphere, a, with electricity by induction exerted by the electricity in the sphere, b.

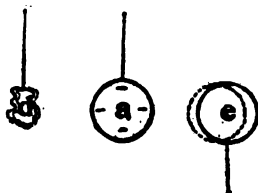
the negative moving to the side nearest C, by reason of C's attraction, while the positive is repelled to the opposite side, as may be seen by the signs plus and minus.

For unlike attracts and like repels. Separation is one of the chief mysteries of nature, and always precedes attraction. The ball C must not be allowed to touch A under any circumstances, for then A would be charged by conduction—not induction. At this point, gradually bring B to the position shown. Lightning will dash across the space between with a snapping sound. The positive on A flies to B, and soon as this occurs the sphere B must be removed, and C also, leaving A alone in the air.

Now, since man began to handle electricity nothing more wonderful than this has been seen by mortal eye, nor ought that seems to approach nearer the confines of nature than the strange property now possessed by the sphere A.

LAW—Electricity on its surface has power to attract and cause motion in every mode of matter.

This activity is shown in cut 122, where a and d are suspended as before, while e is a hydrogen toy balloon attached to a peg below. By reason of the experiment, a was charged negatively; but by the same method it might have been endowed with positive, in either case it will attract any substance known. This is shown in the mass d, which has been tried with wood, stone, glass, metal,



CUT 122—The charge sphere, a, attracting and causing motion in any known mode of matter, d, and also in a hydrogen balloon, e.

tallow, paraffine, oil, rubber, paper and other substances, and they all move toward a as shown by dotted outlines. Gases are also attracted as in the case of the hydrogen in e. If the shape of d is unsymmetrical with regard to its center of mass it will also rotate on an axis. If a is moved around d in a circle d will rotate at the same rate, following every motion of a. Let a be removed to a distant part of the room. Then d will still continue to turn until brought to a rest by friction of air and torsion of the thread.

LAW—The mass d in a vacuum would rotate forever.

And the hypothesis of archaic induction is advanced here with the hope that obscure cosmological problems may be cleared. In cut 123, the principles of inductance, separation and attraction wrought by static electricity are transferred from the physical laboratory to the primitive and formative cosmical masses after they had advanced from the original corpuscular state to widely separated and slightly condensed nebulæ. Let the nebula

a be negatively charged as in cut 121. Lightning is seen escaping in a positive charge to the nebula at the left. Then let nebula a, carrying its wonderful power of attraction, in addition to its inherent gravity, wander among its neighbors at random. Let it pass b in the lower portion of the sphere. It will separate the electricity in b and the total negative quantity in a will attract the positive and repel the negative in b, forming a mechanical couple, and cause b to rotate in the direction of the arrow.



[Cut 123. The Negatively charged Nebula A, is supposed to cause rotation in B by Electrical Attraction.

For there is no more reason to doubt that electricity was present in vast quantities in the primitive nebulae than to doubt that it is in intense activity in terrestrial clouds of vapor. In early stages of evolution before suns appeared the most appalling lightnings flashed from nebulae to nebulae, whose dimensions in many cases then, as are plainly seen now, were hundreds—yea, thousands of times larger than that vast nebula whence our own sun was formed.

What mighty import hovers round the word evolution. For giant modes of energy wrought and struggled in war. Matter was shaken, oscillated, kneaded, boiled and tumbled in the throes of chaos. Phantom forms of nebulae were clutched in awful

churning, in seething whirlpools, and throbbed with energy. Absolute zero and darkness reigned, useless indeed; cold light can be in the most frigid space.

And silence reigned save from lightning, in the twisting gaseous masses, for friction had scarcely set in. The hosts of *nebulæ* were not yet in the relentless grasp of the Darwinian tides. But when pent up electricity burst all bounds with the concussion as of a hundred worlds of broken glass, primordial thunders rolled—without ear to hear. As soon, therefore, as electricity was separated by induction, one portion escaped by flashing to another; then that nebula had potency and power to move through space and set up rotation in all other *nebulæ* adjacent to its erratic pathway. And some other oppositely induced mass would also cause it to make rotation.

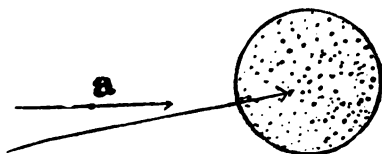
It is known from mechanics that whatever movement of rotation was impressed upon a nebula by another passing it, must be retained forever if space is vacuous. Here is the great law of conservation of areas:

LAW.—When a system of particles, in rotation, changes form or size, the sum of all the areas described by each, in any unit of time, is constant.

This is one corner stone of that edifice, the visible universe. A particle in making one circuit around the center describes a circle which has its own definite area. Now let the diameter of the rotating mass shrink to one-half, and if it still remains a sphere, the area of the circle cut out by the particle in its new position will be only one-fourth. Then it must rotate four times faster to cut out four circles which together will have the same area as the large one. The motion is called areolar velocity. Therefore, the earth now has the same quantity of rotary motion that was imparted it when a rare nebula by the gravity and inductance of some other nebula that passed it in primordial times, less than consumed by tides.

QUANTITY OF MATTER.

In cut 124 let the sphere be such that light, having a known speed of 186,000 miles per second, requires 30,000 years to traverse its diameter. Imagine the sphere to contain 500,000,000 suns, each containing the same quantity of matter now stored in our sun, and let them be uniformly distributed as shown. Consider *a* to be a stone or sun falling from infinite space—that is, it has fallen forever. Of course, the two words infinite and forever make no impress of their true meaning on such weak minds as those now possessed by man. For man is ignorant concerning duration and space. It can be shown by rigid mathe-



Cut 124. Sphere of Suns and Dark Bodies, whose diameter is such that light moving 186,000 miles per second, requires 30,000 years to traverse.

matics, and has been by Newcomb and others, that the final velocity on arriving at the center of mass of the sphere of suns would be twenty-five miles per second. But the sun 1,830 Groombridge is now seen to be flying with the terrific velocity of 200 miles per second, at least. For Newcomb does not give its parallax in his late work, "The Stars," showing it to be so far away that astronomers are unable to measure its distance. Its velocity is beyond doubt more than 200 miles per second. This leads to the most remarkable conclusion regarding the quantity of matter within the 30,000 light year circle or sphere.

ACTIVITY AND VELOCITY.

From dynamical laws it is known that it requires four times the force to double the speed of a falling body. Thus doubling the motion to fifty miles per second requires four times the num-

ber of suns, or two billion. Doubling again the speed is 100 miles, with eight billion suns. With double this, or the terminal velocity, of 200 miles per second, the number of suns required is thirty-two billion, each one being as massive as our sun. The graphic plates with long exposure, even to the faintest magnitudes able to make impressions, show less than 125,000,000 and more than 100,000,000 suns. Admitting that each contains as much matter as the sun, then only one in 320 emits light strong enough to impress the most sensitive plates. But our sun contains sufficient quantity of the matter to make 333,000 worlds of the size and density of the earth. Then 333,000 multiplied by thirty-two billions equals the mass of eleven quadrillion bodies like the earth attracting the flying star. The visible sidereal structure is of inconceivable antiquity and is far more massive than thought possible.

Blackened death has encountered most all the suns; only one in 320 is now emitting life-giving heat and light, or being present to throw feeble and fitful gleams on their funeral paths. Another star is now known to be moving faster than 1830 Gr., making the visible and invisible universe still more massive.

SUMMARY.

The latest deductions of science are that evolution set its mighty clutch on all existing matter when it was in an excessively rare ultra-gaseous or corpuscular state, filling all space now occupied by suns. Gravity was the only mode of energy, and the first to act.

Nuclei formed and these attracted adjacent corpuscles forming countless nebulae. These still contracted and grew more dense. Electricity appeared and began the work of building a universe, of rotating suns by induction. Heat and light came later on the primordial cosmical scene of turmoil, save that momentarily appearing at times of the outbursts of electricity. The heat and light evolved by contracting suns came far later, as well as from chemism. Gemination wrought also in nebulae as well as in gaseous and liquid suns, separating one into two. And the process of division continued in planets and their moons. Soon as gemination finished its work producing any two suns, then that mighty and chief builder, the tides, laid hold on the primeval masses and fashioned both into suns and worlds revolving in regular orbits around their centers of mass. Through contraction, heat developed and light on small worlds after nearly all the heat had vanished, water came, and coarse life, then more refined, and lastly mind, along toward the close of evolution. It contemplates the stupendous scene a few seconds and disappears. Each mind gains one or two impressions of the objects on display and dies. Were it not for the custom of recording these fitful

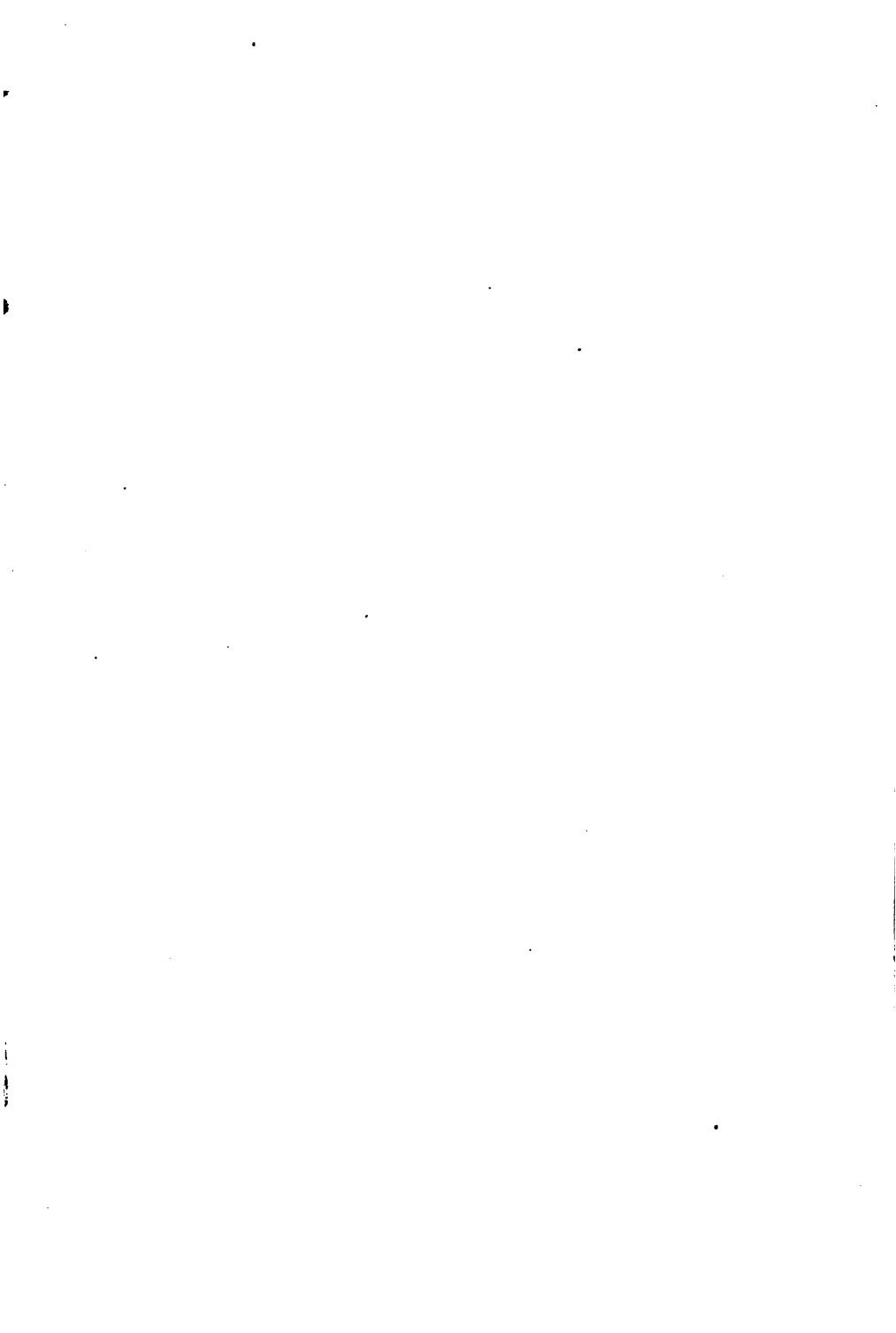
thoughts and ideas, in print, in sculpture, on obelisk and walls, on bricks and cylinders, and now by that marvelous process—making records on graphic plates—ignorance would reign supreme, for it is only by storing minute fragments of knowledge gained by each, that a fund can be accumulated.

Coherent thought in modern times began in 1610, so it is but 300 momentary years since wisdom began to be stored. For the awful and withering poison of the dark ages subverted mind. The three centuries have produced the lens, the calculus, the grating and the graphic plate, four engines with which men are now hourly wresting new and long delayed secrets from nature. Beginning evolution in corpuscular conditions, the universe of matter passes all stages of youth, adolescence, maturity and death, the death consisting of loss of heat. Then if the titanic foundations are torn up and billions of dead suns and frigid worlds are hurled together with the most appalling speed so that heat enough due to collision and friction will be developed, to dissipate all back to corpuscles again, refilling the same space, the total mutation will have constituted one sidereal universe and made all things ready for another. Thus one phase of matter will have been passed the whole constituting one wave as shown in cut 125.



Cut 125. One Wave.

THE END.





LOWE OBSERVATORY

ADDENDA.

The Lowe Observatory.*

The location of this observatory is unique in many respects. It stands on a peak whose apex was cut off abruptly to secure a flat surface for the building. This central summit is in a vast amphitheatre, formed of colossal peaks round about, some on a level with the observatory and others 1200 feet above. On either side are yawning canyons. Rubio on the east, 670 feet deep, descends precipitously from the walls of the observatory; while Los Flores' Gorge makes rapid descent to a depth of 1250 feet on the west. A chain of old Sierra Madre's range is bent and coiled in mighty links enclosing both canyons, the central, or Echo Mountain, and observatory peak, and extends from the southeast round through the east and north, through northwest, and rapidly declines to the west, where the range dwindles into the Verdugo hills overlooking that paradise of oranges, apricots and grapes, the famous La Canada Valley. Still beyond and nearer the sea, eight rows of hills, ranging from north to south, are visible. These are the Tejunga hills and Simi and Santa Monica ranges of low mountains. Speech is impotent to portray the glories of the sunsets from the vernal equinox to the summer solstice and return to the equinox of autumn. The angles made by these ranges with the ecliptic, are such that the declining sun pours its radiant floods between, lighting up the

*From the Bret Harte Memorial Number of the OVERLAND MONTHLY, Sept., 1902.

gloomy and solitary canyons with supernal colors. For dust from waste places on the hills, and from Mojave's desert areas, comes in contact with watery molecules thrust over by the breakers of the Pacific in their dashings against Simi's granite bulwarks, and these absorb and quench some of the waves of light, allowing others to illuminate summits, valleys, canyons and domes with hues and tints, all blending into one stupendous panorama of surpassing loveliness and beauty. So remarkable is this scene that iron railings are placed on the canyon's edge, for travelers from all parts of the earth, who come to behold the sun as it sinks into the sea. It is Sunset Point, Los Flores Canyon. But it is to the mighty and serrated contour of cliffs and peaks that scientific interest is attached. So transparent is the air that minute stars are seen at the absolute instant of rising. Thus the writer never saw a star at the moment of its advent above the horizon, until coming to this enchanted place. Not sorcerer of Egypt or Eleusis ever conjured up a more magnificent spectacle, or weird influence, nor impression more fascinating to mind and sense, than the marvelous display of rising celestial bodies. The great nebula in Orion issues out of a smooth wind and sand-worn rock, and so clear is the air that five stars in the trapezium have been seen standing on stone, while the light of the great nebula suffers but little diminution. Since the telescope reverses all objects, rising stars seem to be going downward toward the earth, and language cannot describe the wonders of the rising—falling—Pleiades, for this glittering host of 1300 stars, as seen in the Lowe telescope, seem to be pouring into old Rubio's cavernous depth. And the unutterable glories of the Galaxy—how see them in a lifetime or how recount their splendors—for illimitable hosts of stars pour in floods into the chasm and this Niagara of stellar diamonds, rubies and sapphires, flows with stately motion into the insatiable recesses below. The edge of Saturn's ring cuts its way up and out of a rocky cliff,

and Jupiter at times sends up a tiny moon before it appears; but last night it escaped from a tangle of manzanita bushes far on the mountain's height. The star Castor is seen double between the leaves and branches of a shrub, while the nebula of Andromeda is always enmeshed in a wilderness of low-growing chaparral. Altogether this clear-cut mountain horizon is so beautiful that description fails and words lose their power.

THE SIDEREAL STRUCTURE WITHOUT THE TELESCOPE.

Many more stars can be seen here without optical aid than from low plains. The observatory is above more than half of the dust layer that encloses the entire earth as an envelope. It is no trouble to see the sixth magnitude stars. The stars burn and blaze with a brilliancy unknown to observers below. Sagitarius and Scorpio hang up their sidereal sheets like a drapery of cloth of pearl over the waves of the Pacific. The Milky Way is whiter than as seen from observatories in Illinois and the East, and the sky blacker. The colors of the stars are on display with greatly increased splendor, and contrast is more pronounced than elsewhere. But all glories pale and faint before that awful and sublime object as seen in the Lowe telescope.

THE STELLAR FLOOR.

The majestic pavement of the universe is surely visible from this observatory. It is the background or foundation of the sidereal structure. It is either made up of countless millions of inconceivably distant stars, or a solid external envelope of nebulous matter. It is beyond the Milky Way, and wider. It is not visible in all parts of the sky, but areas far removed from the Galaxy are filled with it. The general structure of nature is surrounded or clothed with a fabric of pearl; but the delicate texture is rent and torn in thousands of places. The appalling

blackness of space appears in these ragged openings. Cosmical rifts, cracks and seams are seen here in great numbers. Special observation has been made of Scorpio and Sagittarius. Over one hundred rents and jagged openings in the white stellar floor have been seen in these two constellations. Some are clear-cut and small, others large, diffuse, with torn and twisted edges, and these are not jet black within. A film seems to be stretched in front. It is doubtful if the white floor is entirely absent even at the Galactic poles. When taking charge of this observatory, the first thought was a mistake had been made concerning the winding sheet of the visible universe; so nothing was published for one year, to test the seeing in all kinds of weather and conditions of air. It was surmised that the white shimmer and sheen in the distant background of the cosmical sphere, was due to the well-known action of dust causing diffusion of light in the earth's atmosphere. Many tests were made on this point, with the result that the cosmic floor was seen in certain localities, on the same nights, when black space was seen between stars in adjacent and also in distant regions. So it is said that the primordial substructure of the universe is on display here. It is doubtful if long time graphs will show this pavement as well as the eye, for the stars in the foreground will store their light in excess in front of the distant wall. If the azoic rocks of stars or nebulae really exists below and beyond all, then the sidereal edifice is far more magnificent and larger than hitherto thought possible. That is, that portion of the structure visible in telescopes, or on plates, is merely cut out of an original universal nebula.

STARLESS FIELDS.

If the stellar pavement is impressive, what shall be said of those caverns in which no star is seen, nor any nebulous gleam of light. After looking for a long time at the multitude of stars, finer than any sand, or as fine as the granules of silver bromide

on graphic plates, the telescope sweeps into view a space black as ink, the effect on the mind is always startling. It is difficult to account for these openings in the structure of stars, for there must be long, empty tubular spaces extending from the place of the earth, even to the floor of stars. At all events, they are black. Here long exposure of sensitive plates might store light enough to make visible impress, and long-time graphs should be made of central portions of the blackest starless areas. Here is a list of several spaces in the starry pavement:

PHOSPHORESCING AREAS OF THE COSMICAL FLOOR.

Right ascensions.		Declinations.	
H.	M.	Degrees.	Minutes.
3	20	38	30
2	50	9	20
2	30	South 18	50
23	55	56	00
22	00	38	40
21	45	45	30
21	00	South 26	00

Next to the last in the table is notable, for the floor and a starless area are seen in the same field of view, both distinct. The edges of the pavement are smooth, like the rim of a well cut in stone, while the second in the catalogue has rough and distorted boundaries of stars round about the cavern.

STARLESS FIELDS. APPROXIMATE CENTERS.

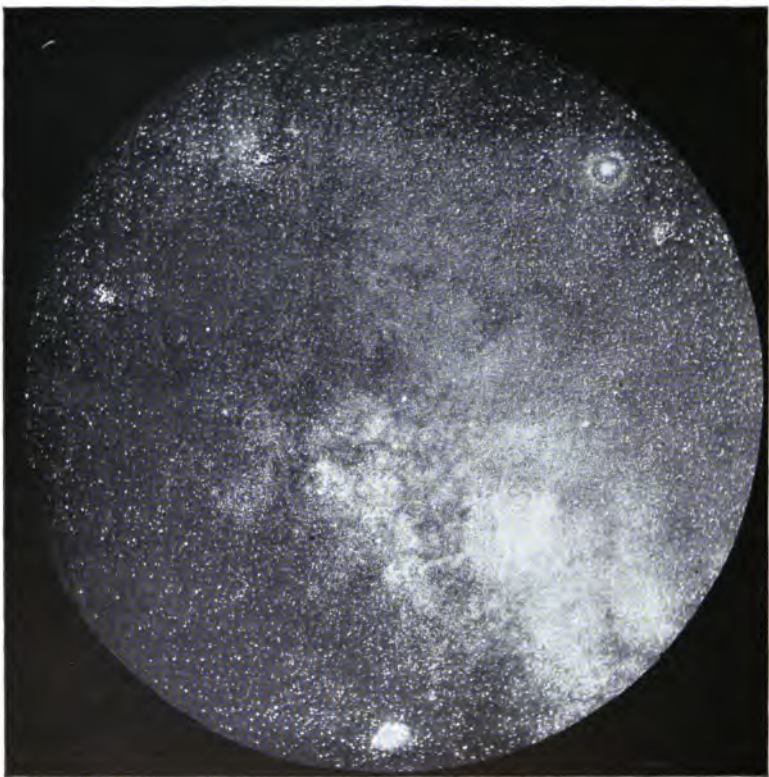
16	50	S 22	20	18	10	S 20	
17	25	S 26	35	18	10	S 18	25
18		S 18	50	18	13	S 18	1
18	3	S 4		5	42	S 8	20

These positions are for the centers of the dark areas. A very large black space is in Scorpio, above the bifurcation of the Milky Way. It is doubtful if any of these places are absolutely black; they seem so to the eye through contrast probably. There is light in all that part of space cut out by the universe. How futile it is to attempt to make drawings or cuts of the shape of the cosmical edifice. Its plan is still unknown. It is well enough, perhaps, to make specifications of the Galaxy and adjacent stars, yet all these are tentative so far. The foundation lower than the Milky Way—the original granite of stars or corpuscles—must be studied and graphed for a century to give an idea of the plan of nature. And then, after all, the problem may appear to be beyond the reach of man. At all events, much attention should be given to this wondrous and original cosmical nebulosity. Nearly all the larger nebulae visible here are complex—those with clear-cut boundaries in small telescopes, show filaments and streamers in the Lowe instrument. The Andromeda nebula displays intricate convolutions, and looks like those shown in recent graphs—having the supposed appearance of a rudimentary solar system.

The trifold nebula presents an infinity of detail not seen in a six-inch telescope, likewise the Omega nebula, while nearly the entire constellation of Orion is simply enshrouded in nebulous sheen, the great central nebula showing a wealth of out-lying wisps, streamers and spray. The dark opening is not dark, for faint light is always seen here. It seems dark by contrast only. There are two filaments extending across the opening at nearly right angles to its length. It is remarkable to have an ocean horizon on the south, for stars rise, cut out small arcs and set in the waves, all within a few minutes in the distant south. The giant sun Canopus thrusts its fiery darts through the mists of the sea, and then vanishes behind the walls of Catalina Island. In coming here from Illinois, Lat. 41 degrees, 13 minutes, to Lat.

34 deg. 17 m., a zone of stars, 7 degrees wide, was lifted up, all new. It has been explored with interest. Not the least among its glories is the wondrous Omega Centauri cluster, where 8,000 fine stars are piled in heaps in a small area. It is impossible for one to form any conception of the splendors of the Milky Way without seeing it in the great glass, and then it is still impossible. The Galactic hosts are splashed and strewn in spray, in spirals, and are tumbled in confusion on a carpet of jet black velvet; or cosmical hail of pearls and diamonds on blackened wastes of space, or piled in heaps, raked into windrows and rolled into banks and bulwarks, all flashing and blazing with supernal colors. These, together with clusters and nebulae, conspire to form a scene surpassing all that mortal eye can ever hope to behold. And beyond all is the primordial base, the cosmic floor. A typical area of the stellar pavement is between the trifid nebula in Sagittarius and nebula No. 6523, Dreyer's N. G. C. The masonry is complete, with no more room for starry sand.

Accompanying this article is a graph of a portion of the Milky Way in the southern constellation, the Centaur, invisible from these latitudes. The ring around the star Beta Centauri is a diffraction ring due to the action of the lenses on light and not actually around the star. The minute specks on the graph are all suns like our own, and the spectroscope shows that they are all composed of the same modes of matter whence our sun and earth are made. One of the chief discoveries of all ages was the fact that all that part of the universe within range of the most powerful telespectrographs is made of the same matter—the sidereal structure is a unit. The black cavernous opening shown to the right and above the star is most awe-inspiring, and, like these seen in great numbers in the fine telescope in this observatory. The object glass is 16 inches in diameter, and the focal length is 22 feet. It was made by Alvan Clark, Sr., with his own ven-



One of the richest regions in the Milky Way in the Constellation Sagittarius, from photograph by Barnard at the Lick Observatory, June 19, 1892.

erable hands. It is simply perfect. The writer had the good fortune to be with Mr. Clark, half a day, in his famous workshop in Cambridgeport, Mass., when he was making the flint lens, and every particular of lens making was explained and shown by this remarkable man. Little did the writer think that he would ever be putting it to active use on the summit of a mountain in that fairy-land—California. This occurred in 1879.

MODERN ASTRONOMY AND ASTROPHYSICS.

The new astronomy is quite unlike the old. The introduction of the spectroscope changed all, and then came the sensitive plate and made another change. The early astronomy contented itself with finding every mathematical law of the solar system and of the external sidereal structure; of finding the mass, volume and density of the sun, planets and satellites, and of a few stars, and continued the work of the practical astronomers, in the computation of the moon's place, for time, and the making of Ephemerides for use in observatories and by sailors, and a vast amount of valuable and necessary work. But now comes the astrophysicist and tells what the stars are made of; writes their history through the eons of the past, and forecasts their future. The capital discovery—stellar evolution—was made by the science of astrophysics. All stars whatever are incandescent suns. They grow from primordial nebulae through infancy, youth, middle life to old age and death. They are now seen in every direction in space, in every possible phase of evolution. Leaves in a forest do not pass so many and varied changes as do the glowing suns. The spectroscope detects every condition, reveals relative ages of suns, and then, that marvelous thing, the graphic plate, catches the fleeting changes, and records them for use for future astronomers. Nature cannot lift a hand anywhere in space within the reach of modern instruments without being instantly graphed. Her most secret laboratories and labyrinths are being explored

hourly. A plate is exposed every hour of the year somewhere on earth. For if the stars are setting at some observatory they are rising or passing the meridian at others. That imperturbable eye—the bromide plate—is always gazing at the stars or sun. Thus, for 1901, graphs were secured of the sun on 361 days.

Astonishing discoveries are now being made, and the great bundle of magazines, monographs, reports of observatories, technical papers, treatises and circulars by the dozen, received almost daily present a most impressive display of the present intense activity of the human mind. Since history began there has not been such incessant labor wrought. And no labor ever performed by the human frame is more arduous and exacting than that hourly engaged in by a working astrophysicist. A trained astronomer is a machine of precision, with every phase of bodily life, every faculty of mind, everything in his being, an abject slave to indomitable will. And that will is immovably set and bent on finding the secrets of the vast cosmical building round about.

RESULTS.

The universe is now known to be a growth. Evolution is seen to set in with the faintest possible rare masses of gaseous nebulae. They condense into smaller and brighter objects. Condensation continues for countless ages, and each becomes a sun. Heat ever escapes, each sun passes its zenith of glory and dies. If a dead sun happens to be drawn into an orbit around a living one, the body so drawn in becomes a planet, and may become inhabited, and undoubtedly will if water appears. Finally both planet and sun expire, and the lifeless planet will still make circuit around its frigid sun and count off useless years—unless there is a resisting medium in space. If so, the revolving world will wind down a spiral and ricochet on the surface of the central sun, the impacts liberating heat again.

The only hope of reanimation of dead suns and ruined worlds

is by wholesale collisions where these bodies by the billion rush to a common center and generate heat enough to dissipate all back to the original corpuscular state again. Countless suns are now seen to be dying from loss of heat, and from motion seen in some notable stars, it is coming to be realized that the quantity of matter now stored in dead worlds is greatly in excess of that in the living. The whole sidereal edifice has been graphed on more than 25,000 plates, in pursuance of the act of the Congress of Astronomers in Paris in 1887. Many of the stellar images on these have been counted under microscopes. If all have the same average, the total number of stars appearing will fall between 100,000,000 and 125,000,000. But assign to each of these any mass within bounds of reason, then by the laws of gravity and motion, it can be shown that they contain only a minute fraction of the entire quantity of existing matter. Hence dark worlds are immensely more numerous than those that are active, giving out heat and light. So that those now shining are mere funeral tapers, lighting up the cheerless and melancholy pathways of ancient suns and forsaken worlds. That part of nature within reach of the best telescopes is of inconceivable antiquity and magnitude. The first and amazing fact encountered by astronomers is that of the interminable space round about. For the nearest neighboring sun to ours is 25 million million miles away, and others are a hundred, yea, a thousand times more distant. In the evolution of suns, so far as science can now see, heat was the first to appear in condensing matter, unless, indeed, electricity, or "cold" light preceded it. Primordial absolute zero, besides which frozen hydrogen and solid blocks of air appear warm, preceded activity. At all events, light succeeds heat. Moisture appeared late in evolution. Then tardy life came upon cool worlds, and that evanescent, transitory and ephemeral, ultimate and final refinement of matter—mind—was the last to appear in the midst of the tremendous cosmic scene. It cannot exist long,

for such worlds as the earth are habitable for an hour or a day only, compared with the duration of a structural universe of matter. So mind and life will be the first to vanish. Absolute zero of temperature is the normal condition of matter and space. For when primordial matter was so attenuated that a volume of it of the size of the earth only contained enough to weigh 127 pounds, it did not retain heat. So heat, light, life and mind appear to be mere episodes in cosmic fluctuations and surging of matter. Astrophysics has shown the earth's place in nature. The dust, of which easily 1,000,000 particles are lying on the page of the *Overland Monthly*, are each as large in proportion to the thickness and area of the magazine, or of the cubical space of the room in which the reader may be, as is the earth to that portion of space included within the envelope of stars at the extreme limit of vision in the 40-inch telescope. These stars are of the seventeenth magnitude, and from photometric observations it is almost certain that they are at least so far distant that light traveling with the known speed of 186,000 miles per second, requires 15,000 years to come hither. This makes the sphere of suns visible in the Lick and Yerkes glasses, 30,000 light years in diameter. The particles of dust, 1,000,000 to the page, are too large. So now, astrophysics has demonstrated its extreme value, for man for the first time on earth knows the earth's place and his own.

THE INCLINED RAILWAY.

Neither Suphis, the monarch builder of Egypt, nor Rameses II., did a greater work than the inclined railway up Echo Mountain. Engineers and railroad contractors from all parts of the world pronounce it to be a model of high-class engineering. Its length is 3,000 feet and vertical ascent of 1,325 feet, with grades of 45, 48, 55 and 62 per cent. Two white chariots balance on one endless steel wire cable, the car Rubio being down, and Echo invisible at the top, to the left of Hotel Chalet in the cut. There



The Inclined Railway, Echo Mountain, California. Length, 3,000 feet. Vertical Ascent 1,325 feet from bottom of Rubio Canyon, to the top of Echo Mountain. Time of ascent of cars, eight minutes.

are three rails with two cars which pass automatically half way up at the switch, which is shown. The great motors are at the top, and are actuated by electricity, brought from the Santa Ana river 90 miles away. The current comes to Pasadena on three wires at a pressure of 33,000 volts, with 50 cycles. Here it is stepped to 2,200 volts and sent to the power house on Echo Mountain, where its potential is again lowered to the usual railway pressure, and made direct by a General Electric Company 20 am-

pere induction motor. In case this circuit should fail, there are dynamos at the foot of the incline in the building to the left, turned by two Pelton wheels, run by water from a reservoir near the observatory, 1,500 feet above. The pressure is terrific, and the struggle of the water to escape its narrow prison, the half-inch nozzle, the hissing and trembling and throbbing of the pent-up force, are impressive. The escaping water has more the appearance of a solid rod of metal than a thin liquid, and would instantly take the life of a man if it struck squarely over the lungs.

The white chariots, Echo and Rubio, making ascent in eight minutes, lift the startled tourist from the gloom lowering in the canyon below to a stupendous transformation scene above. If, as often happens in the rainy season, clouds extend from the depths of the canyon to half the height of the incline—then language—spoken or written—or brush or pencil of artist are impotent to portray the marvelous change that awaits the traveler. Unrivalled splendors burst upon the startled eyes; and not the sumptuous transformation of scene-painters, nor wand of magician, nor witchery of optical illusion, nor spell of enchantress, can equal it.

Under the great tree to the right, at the foot of the incline, is the mouth of Rubio Canyon, hewn in primeval porphyritic rock. It is a rift or gorge in the mountains formed on that auspicious day when good Dame Nature lifted up old Sierra Madre's range, through the bottom of an ancient sea. It extends to a depth of 1,000 feet under the hotel, and continues in sinuous course to the observatory, where its depth is 670 feet. This canyon is wild, and within its jaws nature at first frightens, and threatens to hurl chaotic rocks upon the explorer, and then pleases, dispels fear and woos with ferns, flowers and trailing vines—with cool streams and miniature whirlpools, until one arrives by winding stairs at the foot of Rubio Falls, 100 feet in height. The peaks to the east of the observatory are rightly named Echo Mountains.

They repeat all that is spoken to them, and if one stands in the right place he hears seven echoes. The colossal walls met with a surprise last spring. The great singer, Calve, came and sang and poured forth her wealth of song. The startled rocks were taken all unawares, and at first, were abashed. For nameless centuries they had not heard sound save that of hoarse notes of raging elemental war. Their chagrin and discomfiture remained for a moment only, when they relaxed their stony throats, and answering, gave back all the marvelous tones.

The great circular bridge far above the observatory on the road to Mount Lowe is also a marvel of engineering. The view from Lowe Observatory is one of beauty and magnificence. The land area visible is 900 square miles. In every direction the land is arranged in squares and parallelograms, planted to oranges, lemons, apricots, olives, prunes, peaches, figs, nectarines, almonds, grapes, and walnuts. Kaleidoscopic changes of color succeed in the flowers and leaves throughout the year. The green is perpetual. The entire valley is a scene of intense activity from Christmas to May, gathering, packing and shipping oranges and lemons. In summer the apricot harvest is a sight to behold, and in autumn it is difficult to secure workers to gather the tons of grapes. The writer dare not attempt to describe the climate. One must live here to form any conception of its loveliness. The extensive ocean front is being transformed into a continuous summer resort for miles, as fast as money and men can build cottages, bath houses, wharves, walks and everything else, like Atlantic City, Long Branch, and all other Eastern beaches. Cloud effects on Mt. Lowe in the rainy period are a never ending source of wonder. Thus one may be reading near a window in bright sunshine. Suddenly the printed page grows dim, a cloud has condensed in space round the building and against the window pane. Sunsets have been attempted by artists, and also by able writers, who handle words as one would sticks and stones, but both find



View on the mountains between the Observatory and base of Mount Lowe. The Circular Bridge appears. Far to the south extends the lovely San Gabriel Valley, even to the sea.

their powers begin to fail and wane. When the entire land and sea are covered with clouds, say from 100 to 1000 feet below the observatory, the top layer is simply indescribable in its supernal glory. It is then the sun is supreme in its inconceivable majesty and splendor, for the earth is invisible. And again, it is no occasion for surprise that our own great ancestors—the Aryans—worshiped the solar globe.

GREAT ELECTRIC STORM.

A most appalling electric storm raged here during four hours on the night of June 10, 1902. No rain fell. It was a remarkable conflict of lightning and riven peaks. Terrific flashes of chain lightning burst forth from inky clouds at the rate of two per minute during the four eventful hours. The thunders of Gettysburg and Chicamauga roared and crashed round the frightened summits and bellowed to the lowest canyon's depths. The awful turbulence of Mount Pelee was repeated, perhaps as far as electricity could imitate that upheaval. Lightning was seen to strike peaks many times. One bolt fell close to the observatory, and one struck the Chalet Hotel. The vast cloud masses came from the northeast. After bombarding the mountain for three hours, the entire mass moved southwest and became depressed perhaps a thousand feet. This had the effect of making the center of the storm appear to be on a level with the observatory, with the astonishing experience of beholding the top and side of a terrible battle of electricity. The sinister monster—the widening cloud—spread over Pasadena and Los Angeles. The explosions of electricity were almost continuous with each streak of vertical lightning. It seemed that both cities were doomed to certain destruction. This display, awful in its grandeur, kept up for one hour, then moved away, and hurled its furious rage upon the sea and rushed towards that bulwark, the



Observatory, Summit of Echo Mountain and the San Gabriel Valley. The Pacific Ocean in the south.
Taken before the addition of Science Hall to the Observatory.

mountain island of Catalina. No damage was sustained by either city, while a slight but welcome rain fell.

NOVEMBER METEORS.

The literature of the world recounts the glories of the shower of meteors as seen at Niagara Falls on November 13, 1833. But whatever splendors were beheld there, they could not be more magnificent than the impressive display on this silent and solitary peak from midnight to dawn on November 15, 1901. It was a fire of shot and shell, from one to five per minute—a celestial battle—entirely without sound. This intense silence made the scene one of the utmost sublimity, and the effect on one's mind cannot be conveyed to another. Swords, scimiters and flashing spears were thrust against a hundred lightning-scarred and sand-sculptured summits. Vast bombs, aimed at peaks, burst into glittering fragments, only to be succeeded by others, some aimed, so it seemed, directly at the white dome of the observatory. Others shot with terrific speed into the wilderness of electric lights in the slumbering city below, and still others hurled themselves into the sea, or sought to throw down the battlements of Santa Monica mountains in the distant west, or disrupt the walls of Catalina in the south. Of course, these effects were due to perspective, not one being, doubtless, within fifty miles of the earth. The wondrous apparition was on display until the advancing splendors of the sun came on and put out the light of all lesser glories. During this memorable shower, 661 meteors of all sizes were counted. The writer was alone in the majestic solitude, and therefore saw at the most only one-fourth of the entire fall. Referring again to the impressive silence, it is well to say that it makes powerful impress on the mind. At the midnight hour, the stillness is so profound, that by a slight excess of mental imagery, one might think he heard sound issuing forth from the axis of the earth in its turn-



Cloud effects as seen from the Lowe Observatory. These display gorgeous colors at sunrise and sunset.

ing. Nature sets up opposition everywhere and it is a study to see the rivalry between the humming birds and bees for honey on the mountain slopes, laden with their burdens of flowers. So, to geologists, biologists, entomologists, botanists, mineralogists, microscopists, metereologists, naturalists, lovers of nature in her most splendid forms and modes, students of the sea, growers of fruit, engineers, electricians, railroad builders, mountain climbers, explorers, spectroscopists, photographers, artists and astronomers, it is said, come to this wondrous place—Echo Mountain. For:

“To him who in the love of nature holds
Communion with her visible forms,
She speaks a various language.”

But she speaks not in more tongues than here; strange dialects of nature—speech seem to come up from the canyons, and new words of wisdom from the mountain walls. Nature teaches in the midnight hour, and repeats her lesson until solar glories appear in the East. Runic writings, Egyptian glyphs and Cuneiform script are everywhere impressed on plants, in the canyon's abyss, on the mountain sides, in the vale below, and amid the labyrinths of space between the stars above. And had Bret Harte, the lover of nature in all her varying moods, whether lowly or magnificent—California modes—which he made his own; had that poet of nature, who sang of her splendors amid “the pines by the sea,” or “in the valley below,” or beheld some nature-glory “across the distant unfathomable reach,” stood here at sunset point on the canyon's brink, to see a day die; had Bret Harte been here on this summit in fairyland when lightning flashed, or meteors shot across the midnight sky, or had he listened to the voices of nature in the night, issuing forth from gaping canyons or granite walls, had he been here, he would have found words to convey impress of the amazing scenes to

other and waiting minds. For did he not bring pre-historic time to the present when he sang of a cone from one of the gigantic trees of Mariposa, a

“Brown foundling of the Western wood,
Babe of primeval wilderness.
Long on my table hast thou stood
As though ten centuries were not
Imprisoned in thy shining case.”

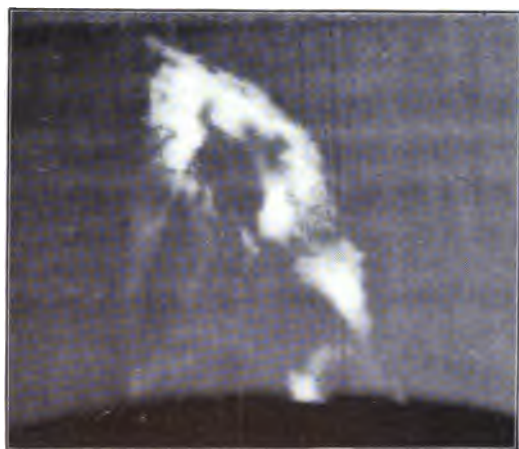
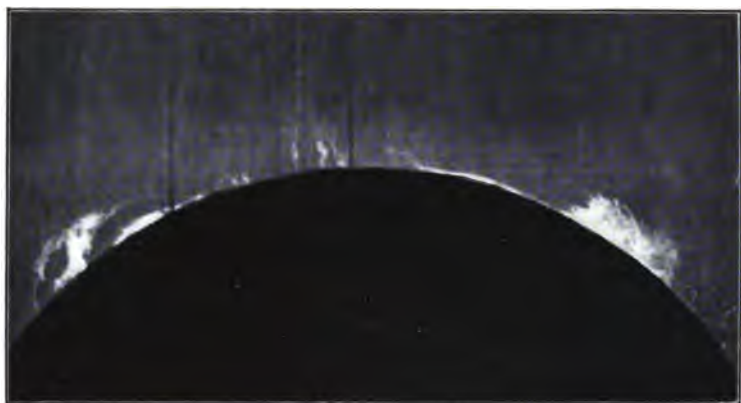
And this—rivaling Burns—in the poem “Hearts Ease:”

“By scattered rocks and turbid waters shifting,
By furrowed glade and dell,
To feverish men thy calm, sweet face uplifting,
Thou stayest them to tell
The delicate thought that cannot find expression,
For ruder speech too fair,
That, like petals, trembles in possession,
And scatters in the air.
The miner pauses in his rugged labor,
And leaning on his spade,
Laughingly calls unto his comrade-neighbor.
To see thy charms displayed.”

LOWE OBSERVATORY.

The telescope and other instruments were brought to Echo Mountain, California, and installed in the Lowe Observatory in August, 1894. They were taken from the Warner Observatory in Rochester, New York. Dr. Swift was director of that institution from its foundation. The addition of electric lights to the city spoiled the definition in telescope of all faint objects in the sky. Prof. T. S. C. Lowe then secured both instruments and astronomer for Southern California. Here the air is pure and definition perfect. Dr. Swift came with all the apparatus, superintended the erection of the observatory and the mounting of the telescope on its pier. He remained director of the Lowe Observatory until December 31, 1900. Many of his famous discoveries of nebulae were made here. During his long and elaborate exploration of the heavens, he discovered, measured their positions, and catalogued 1302 nebulae, about half of these being discovered at the Lowe Observatory. He also discovered thirteen comets, several being detected from this mountain top. He retired laden with honors at the age of eighty-three years.

The comprehensive plan of establishing a well-equipped astronomical observatory on the summit of Echo Mountain, at a high altitude and under the cloudless skies of far-famed Southern California in an atmosphere where clearness of vision and steadiness of observation could be depended upon to furnish their aid in furthering the advancement of human knowledge, is entirely due to the untiring efforts and devotion to science of a man whose name has become a household word—Professor T. S. C. Lowe.



PHOTOGRAPHS OF SOLAR PROMINENCES.
Taken at the Yerkes Observatory by Mr. Ferdinand Ellerman.
Altitude of Prominence in lower view, 185,000 miles.

Any handbook of the Lowe Observatory, or publication involving the scientific research of this institution, would not be complete without a sketch of this remarkable man, who at the age of seventy, when most men are wont to retire from the normal occupations of life, has been found planning for Southern California an institution of research and learning of which the Astronomical Observatory of Echo Mountain was but to be the initial step. It is to be hoped in the interests of science and in the interests of the fair name of Southern California that the plans of this institution which have been slowly but surely evolving in the mind of this great man may during his lifetime be carried to a concrete issue. In the meantime it may be truly said that he has in two ways left an indelible impress on the community in which he has chosen his abode. First, through his connection with and the construction of the great engineering achievement, the Mount Lowe railway, and second, through his carrying to a successful finish, the Astronomical Observatory on Echo Mountain, which bears his name. The former marks an epoch in the material advancement of Southern California; the latter points with pride to the *pari passu* advancement of a love for science in our section of the country.

Born in New Hampshire in the year 1832 from old New England stock, he inherited from his parents all the sturdy qualifications for which the descendants of the pilgrims have become so well known.

It was at an early age that his attention was turned to the sciences, and especially to the subject of meteorology. A question confronted him involving the probability of the existence of permanent air currents in the upper strata of the earth's atmosphere, air currents which in his opinion must necessarily exist and be moving in a direction parallel to the earth's rotation on its axis. He gave much of his time and talent to this fascinating subject. After long and serious deliberation he concluded that

the only method of solving the problem was to ascend in a balloon to an altitude above the earth's surface sufficiently high to attain the specific conditions.

It was this that led Professor Lowe's attention to aeronautics, and on the 20th of April, 1861, at 4 o'clock in the morning we find him leaving Cincinnati in a balloon. The voyage was a remarkable one, it being not only the longest, but also the quickest aeronautic excursion on record. At noon on the same day he left Cincinnati he arrived at the Atlantic coast in the latitude of South Carolina. A remarkable voyage of 1000 miles had been performed in eight hours. The existence of the upper air currents became an established fact.

The attention of the United States government was attracted by this remarkable feat. Professor Lowe's services were enlisted for the organization of an army balloon corps. Rapid progress was made in the improvement of balloons for war purposes. It was found that this service under the direction of Professor Lowe became an invaluable aid in observing the movements of the enemy during the civil war.

At some time during the sixties he turned his attention to other inventions which have proven to be of great value to mankind. The first patents for machinery for making ice artificially and for refrigerating in general were awarded to him in the year 1867.

Again, the discovery of the process and method of making illuminating gas by what is known as the Lowe Water Gas System is due entirely to his inventive genius. This system has been perfected and is in use in nearly every large city in the United States.

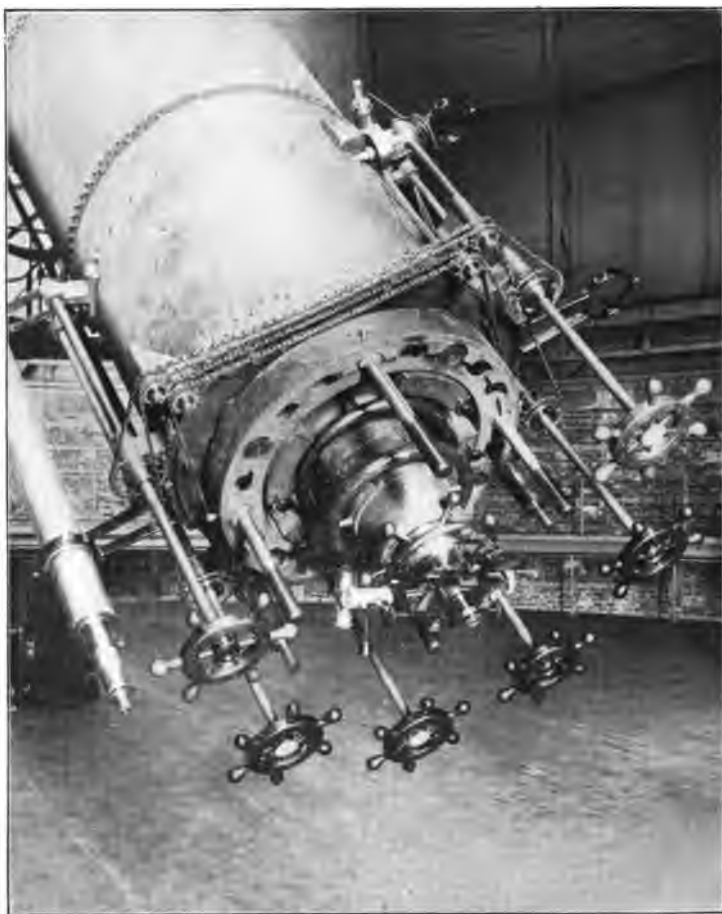
These are but a few of Professor T. S. C. Lowe's contributions to the intellectual and material advancement of his fellowmen. In times to come, generations hence, mankind will continue to benefit by the results of his scientific activity.



SPECTRA OF THE NEW STAR IN PERSEUS,
SHOWING ITS EVOLUTION.



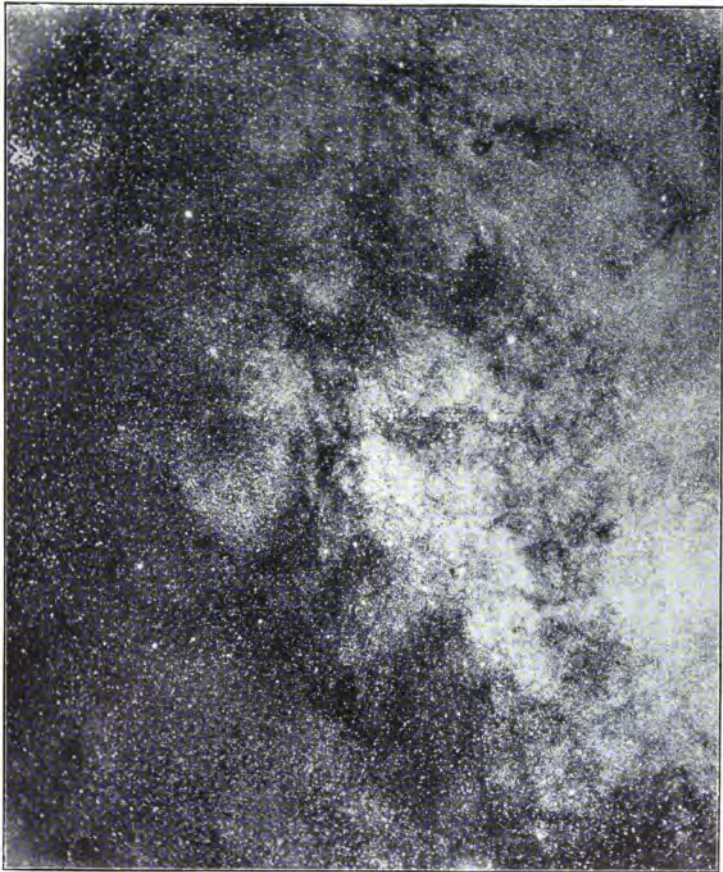
PROFESSOR BARNARD'S PHOTOGRAPH OF A DENSE REGION
IN THE GALAXY.



EYE END OF THE YERKES 40-INCH TELESCOPE,
WILLIAMS BAY, WISCONSIN.
Property of the University of Chicago.



THE GREAT NEBULA IN ORION.
Photograph by Professor E. E. Barnard.



PROFESSOR E. E. BARNARD'S PHOTOGRAPH OF A RICH
REGION IN THE MILKY WAY.



Lowe Observatory taken on a dark night by means of the Electrical Searchlight, distance, 1800 feet. Exposure 3 minutes.
(Cut by courtesy of the Photographic Times Bulletin, New York.)



The Lowe Telescope. Diameter of Object Glass, 16 inches; Focal length, 22 feet.
Made by Alvan Clark & Sons, Cambridgeport, Massachusetts.

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Cut 46, page 112, is bottom up.

Cut 60, page 140, ~~Crooke's Tubes~~, should read: "Geisler's."

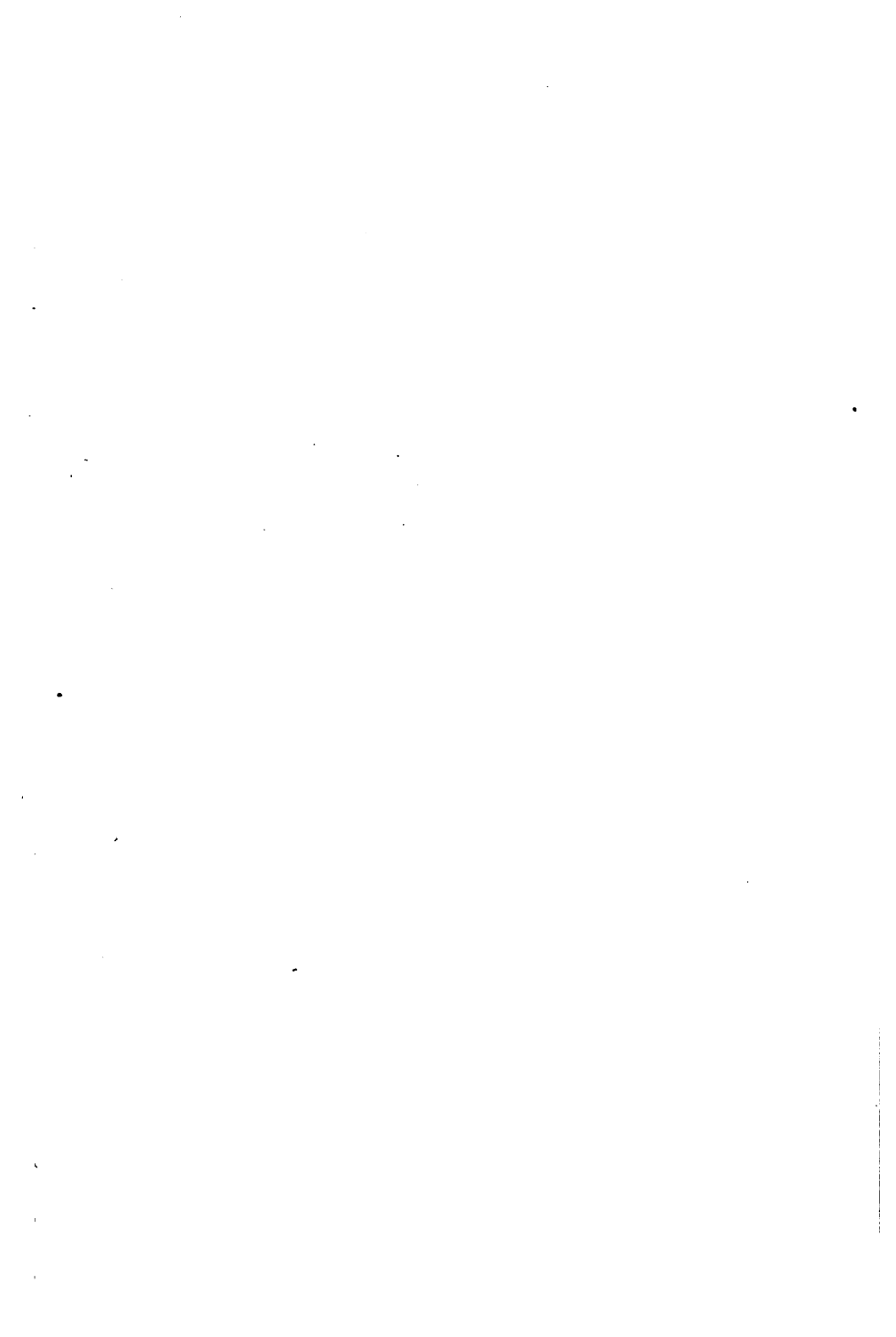
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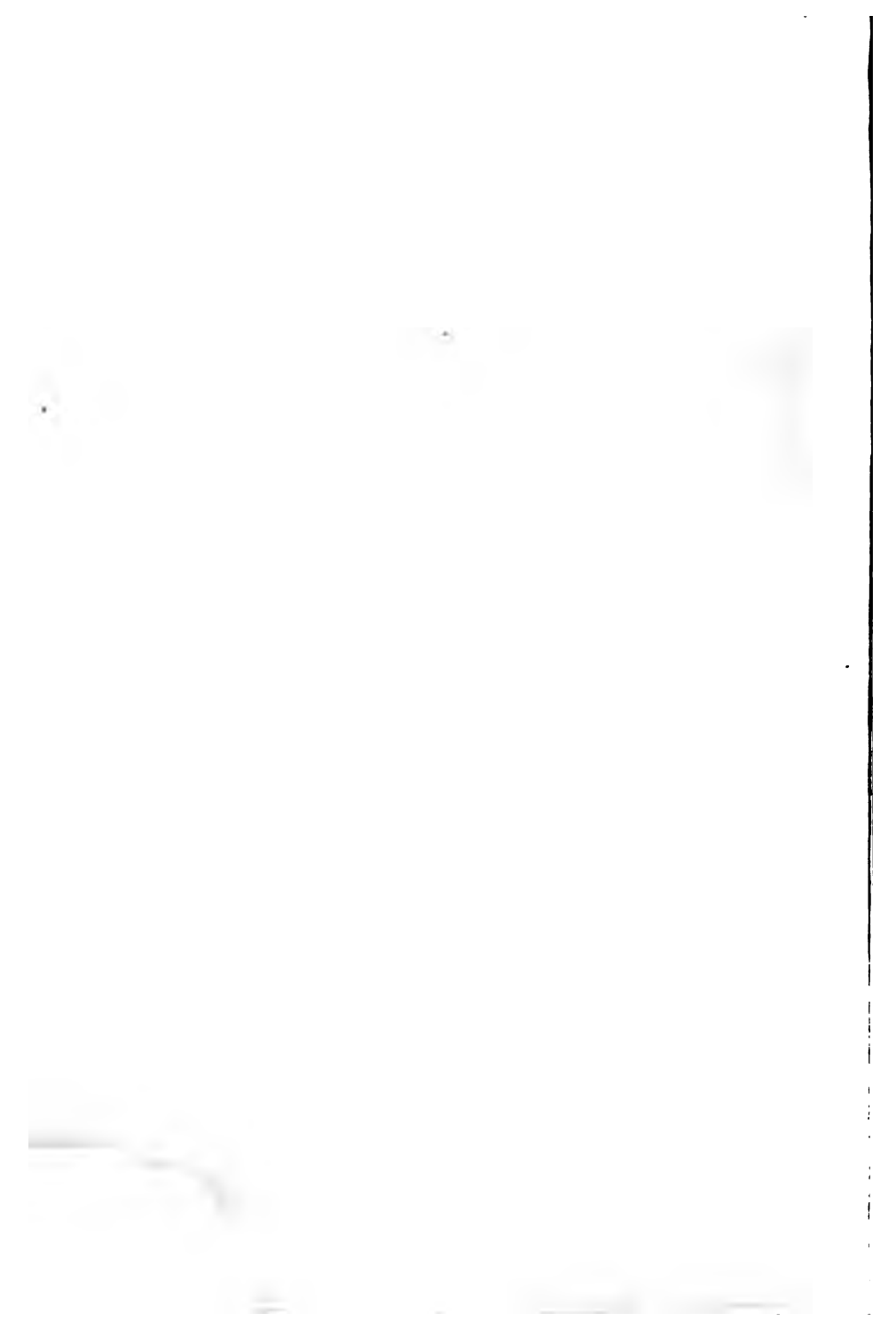
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